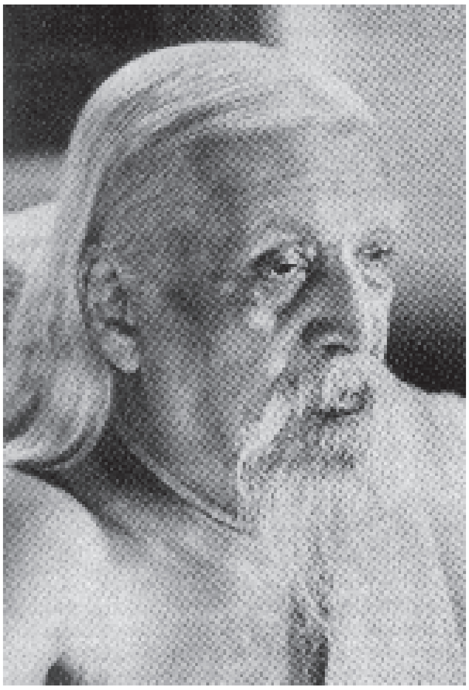
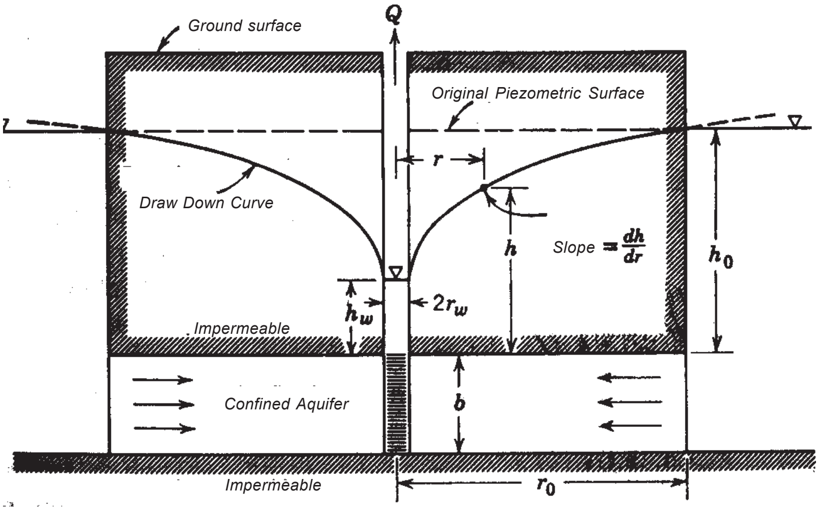


Sri Aurobindo

Thy embrace which rends the living knot of pain,
Thy joy, O Lord, in which all creatures breathe,
Thy magic flowing waters of deep love,
Thy sweetness give to me for earth and men.

Basic Principles of Hydrogeology



Cone of depression

Rao R.M.
Subrahmanyam A.

© Authors

i. R. MOHANA RAO, M.Sc.,
Lecturer, Department of Geology
V.R.S. & Y.R.N. College, Chirala.

ii. Dr. A. SUBRAHMANYAM, M.Sc., Ph.D.,
Head, Department of Geology
Hindu College, Guntur

First Edition : April 1999

Price : Rs. 40 /-

All Rights Reserved
No part of this book may be reproduced, stored in a retrieval system or transmitted in any form or by any means, or translated, without the prior permission in writing of R. MOHANA RAO nor be otherwise circulated in any form of binding or cover other than that in which it is published and without a similar condition including this conditon being imposed on the subsequent purchaser.

PUBLISHER
SADHANA GRANDHA MANDALI
TENALI - 522 201, A.P.

D.T.P. by
✮✲✬✡✳✥✲✰✲✩✮✶✳
CHIRALA - 523 155
☎ : 08594-36086

PRINTED at
Jyothi Off-set Printers
Kothapeta.
Chirala.

PREFACE

Ground water is one of the natural resources and is essential for human consumption and also useful in all aspects.Searching for its localization is a hazardous task and the real intrinsic charm does lie in the success of the ground water structures for which the integrated hydrogeological and Geophysical surveys are promising and encouraging.

I feel it a great privilege as an experienced Field Geologist of Hydrogeology in the department for giving my compliments in the form of preface to this book. The authors have carefully and precisely tackled the fundamentals so as to facilitate the students to assimilate the disseminated knowledge of Hydrogeology. In the Earth Sciences, as in other branches, knowledge is expanding by leaps and bounds and the students are bewildered. Hence the practical approach is given prime importance with exemplary cases in the light of utilitarian aspects of the subject, keeping in view the environmental conditions. This book is very useful for the beginners of Hydrogeology to stabilize their foundation in the subject. The essence of the field experiences narrated in the book is also helpful for the Field officers.

I am very thankful to the authors for the excellent work rendered by them in writing such a comprehensive text for their students.

Dt.19-4-99
Ongole.

MAKKENA ANJANEYULU
Assist Director (Retd.)
Ground Water Department, A.P.

PROLOGUE

The Prime utility of the book is mentiond in the preface itself by ***Mr. Makkena Anjaneyulu,*** *Assistant Director(retired) Ground water department A.P. to whom we are very grateful for the suggestions and his guidance in the light of field experiences by which the quality and get up of the book is enhanced.*

This book is prepared in accordance with the syllabus (C.C) prescribed by the Universities in Andra Pradesh for undergraduate students who study Geology, as one of the subjects under part II.

We thank Sri V.V. Ramachandra Vasu, President, Smt J. Lakshmi Bhavani, Secretary & Correspondent, and Sri P.G. Sankara Rao, Principal of VRS & YRN College, Chirala; and Sri Madhavapeddi Radha Krishna Murthy, President, Dr. Mannava Radha Krishna Murthy, Sectetary and Correspondent and Sri C. Rama Chandra Rao, Principal of Hindu College, Guntur, for according us permission and encouragement to bring out this book.

Thanks are also due to i) The publisher, Sri Bulusu Surya Prakasa Sastry, Sadhana Grandha Mandali, Tenali ii) The proprietor of Jyothi Offset Printers, Kothapeta iii) Sri C. Subba Rao for his corrective suggestions.

This book is broughtout on the eve of Dr. J.V.Subba Rao's retirement, Head, Dept.of Geology, VRS &YRN College, Chirala.

This book has a special chapter, which will not be found in the books of this type, named as 'ON FIELD' which gives much information on the problems in the field and how to encounter.

There is another special chapter in which different aspects of groundwater conditions of Prakasam District are dealt with as an example.

As and when the needy utilize this book to quench their thirst of groundwater, We dwell in Ecstasy.

All this is the grace of Sri Aurobindo's ***Savitri.***

- Authors

Dedicated
to
KRISHNA

CONTENTS

Chapter 0

Introduction - Definition - Scope and applications of Hydrogeology... 11

Chapter 1

Hydrologic cycle - Definition - Explanation - Equation - Figure - precipitation - Evaporation - Infiltration - Runoff... 14

Chapter 2

Origin - Occurrence - Vertical distribution - Forms of Ground Water - Utilisation.. 19

Chapter 3

Aquifers - Types of Aquifers - Figures - Aquiclude - Aquifuge - Aquitard... 29

Chapter 4

Water-bearing and water-yielding properties of rocks - Introduction - Porosity - Permeability - Darcy's law - Specific yield - Specific Retention etc... 33

Chapter 5

Quality of Ground Water - Physical Quality - Chemical Quality - Quality of Ground Water for domestic and Irrigation use... 40

Chapter 6

Pollution of Ground Water - Causes and Sources of Pollution. 48

Chapter 7

Exploration of Ground Water - Hydrogeological Exploration - Geophysical Exploration... 53

Chapter 8

Artificial recharge of Ground Water - Introduction - Different methods - Watersheds & their Hydrogeological significance... 61

Chapter 9

Seawater Intrusion - Definition - Ghyben-Herzberg relation... 64

Chapter 10

Management of Ground Water - Introduction - Definition of Ground water basin - Concept of Basin Investigations - Basin Yields - Basin Management by conjuctive use... 66

Chapter 11

Ground Water Provinces of India - Introduction - Peninsular Provinces - Ganges - Brahmaputra Alluvial Province - Himalayan Highland Province... 69

Chapter 12

Ground Water Provinces of A.P. - Introduction - Precambrian Crystalline Province - Precambrian Sedimentary Province - Gondwana Sedimentary Province - Deccan trap Province - Cenozoic Province.. 74

Chapter 13

Ground Water Probabilities of Prakasam Dt. - Introduction - Crystallines - Cuddapahs - Gondwanas - Laterites and Alluvium 78

Chapter 14

On Field - Ground Water Problems as assesed from field experiences.. 83

Chapter 15

What's What - Brief Information to Technical terms... 87

Appendix 1

Cone of Depression 91

Appendix 2

Conversion Factors and Constants... 92

Appendix 3

Planets in Solar System.. 93

Subject Index... 94

Bibliography... 96

Chapter 0

INTRODUCTION,
SCOPE AND APPLICATIONS OF HYDROGEOLOGY

Definition
Scope and Application
Interdisciplinary Approach
Environmental Planning
Scope for Development of Ground Water Resources

DEFINITION:

Hydrogeology may be defined as the science dealing with the study of occurrence, distribution, movements and chemistry of all waters of the Earth.

Hydrogeology encompasses the inter-relationships of geological materials and process with water. A similar term Geohydrology is sometimes used as synonym for Hydrogeology. But this term is restricted to engineering field dealling with subsurface fluid hydrology.

Hydrology may be defined as the science of water and does deal with the occurrence, circulation and distribution of water of the earth and its atmosphere. As a branch of Earth science it is concerned with water in streams, lakes and rainfall water occurrences below the surface of the earth in the pores of soil and rocks.

SCOPE AND APPLICATIONS OF HYDROGEOLOGY:

Water occurring, in the voids within a geological stratum is known as ground water.

This saturated zone is to be distinguished from unsaturated zone where voids are filled with water and air. Water contained in saturated zone is important for engineering works, geological studies and water supply developments. Unsaturated zones are usually found above saturated zones and extend upward to the ground surface because this water includes soil moisture within the root zone. It is a major concern of Agriculture, Botany and Soil science.

Petroleum Engineering:

Ground water plays an important part in petroleum engineering. Two fluid systems involving oil and water, and three fluid systems involving gas, oil and water occur frequently in the development of petroleum. Ground water hydrology has gained importance from research conducted by petroleum industry.

INTERDISCIPLINARY APPROACH:

Hydrogeology is an interdisciplinary field . The Hydrogeologist usually has training in Geology, Hydrology, Chemistry, Mathematics and Geo-Physics. Hydrogeologists are also being trained in such areas of engineering as Fluid Mechanics as well as in Computer science. Such training is necessary as Hydrogeologists must be able to communicate effectively with Engineers, Planners, Ecologists, Resource-Managers and other professionals. An understanding of the basic principles of Hydrogeology is useful to Soil Scientists, Engineers, Planners, Foresters and others in similar fields. Modelling of hydrologic systems is another area requiring knowledge of a number of disciplines. Hydrogeologists are being employed as problem solvers and decision-makers. They need to identify a problem, define the data needs, design a field program for collection of data, propose alternative solutions to the problems and implement the preferred solution.

ENVIRONMENTAL PLANNING:

Hydrogeology is also being recognized by both Hydrogeologists and Planners as an important part of environmental planning. As population and economic growth expand, human use of the natural environment is becoming more intense. Incidents of environmental degradation are less likely to occur when the Planner and Hydrogeologist work together.

SCOPE FOR THE DEVELOPMENT OF GROUND WATER RESOURCES:

The role of a Hydrogeologist is to locate and develop the ground water supplies in many parts of the world. There is an urgent need for the development of new ground water supplies. Surface water supplies are especially susceptible to bacterial and viral contamination especially where sanitation is primitive. Droughts in some areas of Africa has now persisted for a genearation. In-expensive water walls in such areas can be virtual life-savers.

In many developed countries disposal of industrial and municipal water has resulted in the contamination of ground water with such things as hydrocarbons, pesticides, insecticides, fertilizers, radionuclides, organic solvents and metals. Agriculture practices have also resulted in degradation of ground and surface water as have septic tanks, road salting, municipal land filling and mining.

Hydrogeological study is an important part of the overall analysis of sites proposed for major construction projects. Coal and nuclear power plants, dams, tunnels, pumped storage reservoirs, and land treatment systems for waste water are typical examples of such projects. Solution mining of water soluble uranium ore is another application of Hydrogeology. Hydrogeology is also fundamental to environmental impact analysis.

SCOPE OF HYDROLOGY:

Hydrology has many practical applications in structural design, irrigation, water supply, waste water disposal and treatment, drainage, flood control, navigation, erosion and sediment control and salinity.

As described above,the Hydrological cycle reaches into the atmosphere and traverses the domains of Hydrometeorology, Meteorology and Climatology. In the Hydrosphere, it crosses as embodies the domains of Limnology (Lakes), Cryology (Snow and ice), Glaciology and Oceanography. In the lithosphere, it embodies Agronomy, Hydrogeology, Geohydrology and Geomorphology. As water effects plants as well as animals, the hydrological cycle extends itself into Plant Ecology, Sericulture and Biohydrology. It has its important influence in Agriculture, Forestry, Geography, Watershed management, Political science (Water supply and policy), Economics and Sociology.

❏

Chapter 1

HYDROLOGIC CYCLE

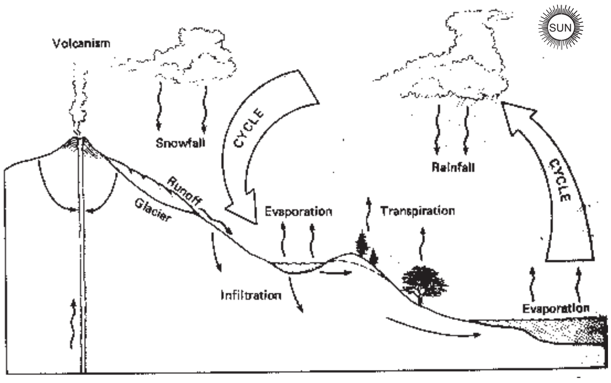
Definition &
Description of Hydrologic Cycle with Figure and Equation
Definitions of

a. Precipitation
b. Evaporation
c. Evapotranspiration
d. Infiltration
e. Runoff

DEFINITION:

The atmosphere, hydrosphere and the upper part of the lithosphere constitute three media in which the water of the earth circulates. This circulation of the water from oceans to the atmosphere, from the atmosphere to the lithosphere, and from the lithosphere to the oceans, occurring through the complex and interdependent processes including precipitation, runoff, ground water flow, evaporation and transpiration is called the Hydrologic Cycle. Solar and planetary forces provide the necessary power for the process. The hydrologic cycle is illustrated in the figure.

The hydrological cycle may be considered to begin with the water of the oceans. Water from the ocean surface is evaporated into the atmosphere. The amount of evaporation of water varies from region to region. Evaporation is greatest near the equator where solar radiation is more intense. Evaporated water is pure, since when it is carried into the atmosphere, the salts of the sea are left behind. Water vapour moves through the atmosphere as an integral part of *weather.* When atmospheric conditions are suitable, water vapour condenses and forms droplets. This phenomenon is called *Precipitation*. Part of the precipitation falls directly on the seas and part of it falls on land surface. A portion of the precipitation that falls on the land is retained temporarily in the soil (soil moisture).



Hydrologic Cycle

Equation:

Precipitation = Runoff + Infilteration + Evaporation + Transpiration

If the surface of the soil is porous, some water will seep into the ground by a process known as 'Infiltration'. Some water moves through the surface channels, reaching rivers, lakes and eventually to the sea. This is called as *Overland flow*. This is also subjected to evaporation and transpiration throughout its movement. The soil moisture may be drawn into the rootlets of growing plants. After the plants use the water, it is transpired as vapour into the atmosphere. This phenomenon is called *Transpiration*.

Excess soil moisture is pulled downward by gravity. At some depth, the soil(or) rock is saturated with water. The top of the saturated zone is called water table. The water that is available below the water table is called *Ground water*. Ground water flows through the rock and soil layers of the earth until it discharges as a spring or seepage into a stream, lake or ocean.

Water flowing in a stream can come from overland flow or from ground water that has seeped into the stream bed. The ground water contribution to a stream is known as *base flow*. The total flow in a stream is termed as *Runoff*.

Evaporation is not restricted to open water bodies such as oceans, lakes, streams and reservoirs.Precipitation intercepted by leaves and other vegetative cover can also evaporate. Water detained in (land surface depressions or soil moisture) the upper layers of the soil also gets evaporated. Direct evaporation of ground water can take place when the saturated zone is at or near the land surface.

The time required for a particle of water to complete a hydrologic cycle can vary considerably. Surface water near the seashore may reach the ocean within a few hours while the portion that reaches the ground water or gets precipitated on the mountains as snow may reach the ocean in years.

Energy Transformations:

The hydrologic cycle is an open system in which solar radiations serve as a source of constant energy. This is most evident in the evaporation and atmospheric circulation of water. The energy of a flowing river is due to the work done by solar energy evaporating water from the ocean surface and lifting it to higher elevations, where it falls to earth. When water changes from one state to another state (liquid, vapour and solid) there is an accompanying change in the heat energy of the water. The heat energy is the amount of thermal energy contained by a substance. Formation of frost and freezing of water result in the release of heat energy.

The transportation of water through the hydrologic cycle and the accompanying heat transfers are vital to the heat balance of the earth. At the equator, the amount of solar radiation is fairly constant throughout the year, while at the poles it varies from zero during the polar winter to amounts greater than those at equator during the polar summer. During the polar winters the land is in shadow, as the sun does not strike the ground. On the other hand, during the summers, the sun shines continuously. In order to balance these anomalies, heat is transferred by currents in the oceans and through the atmosphere as movement of air masses and water vapour. This creates climatic conditions and changing weather patterns that profoundly affect the hydrologic cycle.

DEFINITIONS

Precipitation:-

Precipitation is the atmospheric discharge of water in the solid (hail,snow) (or) liquid (rain) form on the earth’s surface. Some of the precipitation is intercepted by the vegetal canopy (interception) and the rest reaches the surface (through fall). The distribution, duration and intensity and the frequency of occurrence of precipitation are some of the primary factors that govern the distribution of water on the land surface and subsurface.

The precipitation data from a number of adjacent stations can be used to depict isohyetal lines or Isohyets which join all points that receive the same amount of precipitation. An isohyetal map shows the areal distributions of precipitation and forms the basis for computing the total water potential of a region.

Evaporation:

Evaporation is the spontaneous process by which the water is transformed into vaporous state from the surface water bodies, such as sea, lakes, rivers, tanks, glaciers etc. The rate of evaporation depends on several factors. It increases with the decrease in the barometric pressure, increases in air and water temperatures, sun shines, wind velocity, dryness of air and purity of water. Some of these influences are directly or indirectly interrelated. Water is available for evaporation from three different kinds of surfaces:

i. Open water surface
ii. Ground surface
iii. Vegetation

The rate of evaporation under prevailing atmospheric conditions, from a surface of water that is chemically pure and has the temperature of the atmosphere is called the evaporativity or potential rate of evaporation. Evaporation from open water surfaces is estimated by installing evaporation tanks or pans. This may far exceed rainfall in arid and semiarid regions due to low humidity, high temperature and wind speeds.

Transpiration:

Part of the precipitated water intercepted by plants is directly returned to the atmosphere by evaporation and part of the water reaching the ground and making up the soil moisture is evaporated through the leaves by Transpiration. Transpiration rates may be extremely low in Xerophytic plants in deserts but very high in Hydrophytic plants of particular interest are the transpirational losses of potential ground water supplies through Phreatophytes that habitually deplete water from the zone of saturation either directly or through the capillary fringe. The rate of transpiration depends mainly on the species of plant, density of growth, meteorological conditions and moisture content of the soil. In may hydrologic investigations it is impossible to separately determine the water losses by evaporation from soil and water surfaces and interception and transpiration from vegetation. The cumulative loss by evaporation and transpiration is termed as *Evapotranspiration*.

Infiltration:

The infiltration characteristics of the soil determine the rate at which water received as rainfall (or water applied on the surface) can move into the surface. The term percolation is used to denote the transit of infiltrated water through the unsaturated zone. Percolating water follows the path of least resistance, travelling fast under gravity through the larger interconnected voids.

Infiltration rates in soils can be determined in the lab by conducting doublering infiltrometer tests.

Runoff:

Runoff may be defined as the water that falls on the ground flowing from a higher gradient to a lower one. If relatively impervious horizons above the water table outcrop at the land surface, water may flow over them to reach the stream as interflow. Runoff depends on a number of factors, namely

i. Dimensions and configurations of drainage basins.
ii. The climatic conditions including intensity, duration and areal distribution of precipitation.
iii. Moisture content of soil.
iv. Topography and land surface slopes.
v. Infiltration and permeability characteristics of soils and subsurface formations.
vi. Type and density of vegetation.
vii. Aquifer - streams relationship, and
viii. Human activities relating to land use, urbanization.diversion of water, etc.

❑

Chapter 2

ORIGIN, OCCURRENCE, VERTICAL DISTRIBUTION AND FORMS OF GROUND WATER

Origin - Sources and Classification of Ground Water
Occurrence of Ground Water
Vertical Distribution of Ground Water with Figure.
a. Zone of Aeration
b. Zone of Saturation etc.,
Water Table
Forms of Ground Water
Recharge and Discharge Areas
Utilization of Ground Water

Water occupying all the voids with in the geological stratum is known as Ground water. The study of origin and occurrence of ground water is very important in hydrogeological investigations. It is essential to know the sources and classifications of ground water.

ORIGIN:
Sources and Classifications of Ground Water:

Ground water is derived from several sources such as Meteoric, Connate, Marine, Juvenile, etc. The common generic terms used in modern classification are Marine, Meteoric, Connate, Metamorphic (volcanic, Plutonic) , Juvenile. The definitions of these terms are as follows.

Marine Water:

Sea water or ocean water which has invaded rocks and unconsolidated sediments which are in contact with the ocean.

Meteoric Water:

Ground water which originates from precipitation is called

Meteoric water. This water which is initially supplied by the rains or snow as a part of the hydrologic cycle is known as Meteoric water. Part of the rain water infiltrates or percolates downwards below the surface and forms the ground water. The infiltration also takes place from surface water bodies such as rivers, lakes and seas.

Connate Water:

The water that is entrapped in the rocks during their formations due to sedimentation in an aqueous environment, is called Connate water. Many sedimentary rocks are deposited and consolidated under water. Although compaction might squeeze out most of the water initially present in the pores between the grains, yet some water will be retained in the intergranular spaces of such rocks. Such water is known as Connate water. This water may have been derived from oceans or fresh water sources. It is typically highly mineralized. However, this water is of not much importance in yielding supplies for human consumption.

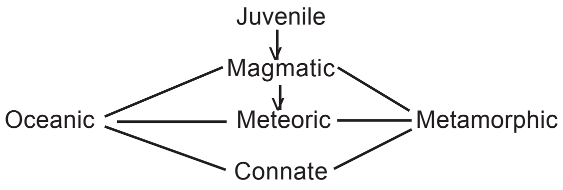
Juvenile Water:

It is also called Magmatic water which is of only theoretical importance. It is the water formed in the cracks or crevices or pores of rocks due to condensation of steam emanating from magmas which exists at places below the surface of the earth. Some hot springs or Geysers are directly of such origin. Plutonic water also belongs to this category which is of deep-seated origin. Volcanic water designates water from relatively shallow depths.

Metamorphic Water :

Water that has been associated with metamorphic rocks during the course of metamorphism is called Metamorphic water. The chief source of ground water is infiltration of meteoric water such as rain water, melted snow and ice, seepage from streams, rivers, lakes, reservoirs, ponds, channels and other water bodies. Other sources of water are of minor importance.

The inter relations of different generic types of ground water is shown in the given figure.



OCCURRENCE OF GROUND WATER:

Ground water occurs in the earth's crust in different forms, depending upon the lithology, stratigraphy and structure. Lithology is the physical make up of mineral composition, grain size and grain packing of the sediments or rocks that make up the geological systems. Stratigraphy describes the geometrical and age relations between various groups, beds and formations in geological systems of sedimentary origin. Structural features such as cleavages, fractures, folds, joints and faults are the geometrical properties of the geological systems produced by deformation after deposition or crystallization. In such consolidated sediments lithology and stratigraphy constitute the most important controls of mode of occurrence of Ground water.

The major geological units in terms of ground water occurrence and potentiality are as described below.

A. Unconsolidated
   i. Fluvial deposits ii. Aeolian deposits iii. Glacial deposits
B. Sedimentary rocks (consolidated)
   i. Sandstones ii. Carbonate rocks iii. Shales
C. Igneous and Metamorphic rocks (crystalline rocks)
D. Volcanic rocks.

Fluvial Deposits:

Fluvial deposits are the materials laid down by physical processes in river channels or on flood plains. The materials are also known as alluvial deposits. Fluvial materials occur in nearly all regions. EX: Meanders, Flood plains.

Aeolian Deposits:

Sediments that are transported and deposited by wind are known as Aeolian deposits. Aeolian deposits consist of sand and silt. Sand dunes form along coasts and in inland areas where rainfall is sparse. In contrast with alluvial, aeolian sands are quite homogeneous in nature.

Glacial Deposits:

They include glacial till, glacio-fluvial sediments, glacio-lacustrine sediments. Glacial till is the most abundant material that was deposited on the land surface during pliestocene time.

In the Precambrian shield region, till is generally sandy with variable amounts of silt and little clay. Glacial till aquifers have generally low permeability characters. Some of the melt water rivers would form aquifer deposits in the same manner as those of alluvial aquifers. Many glaciated areas have deposits of sand and gravel formed on top of masses of stagnant ice during episodes of glacial retreat. These are known as collapsed outwash deposits. It has been observed that clayey or silty, till and glaciolacustrine clay have network of hair line fractures. These fissures are predominantly vertical. These fractures impart enhanced capability of ground water flow.

SEDIMENTARY ROCKS (CONSOLIDATED)

Sandstones:

Sandstone forms the best repositories of ground water. Sandstone beds owe their origin to various depositional environments. Common cementing materials for these sandstones are siliceous, calcareous and argillaceous. These minerals form as a result of precipitation and alter during ground water circulation. Compaction takes place as a result of pressures and temperatures at different depths. We find sandstones with different compaction orders in different geological strata. In general younger sediments are less compact than older ones. The yield and permeability characters therefore vary accordingly. The best sandstone aquifers yield water through their joints and fracture zones. Ex:- Rajahmundry sandstone.

Carbonate rocks:

Carbonate rocks mostly consist of Limestones, Dolomites and Dolomitic lime stones. Geologically young carbonate rocks commonly have porosities that range from 20%to 50% . Many carbonate rocks exhibit secondary porosity as a result of fractures or openings along the bedding planes. The water nearing capacity of carbonate rocks depends upon the secondary openings caused by solution action such as crevices, fissures, sinks, caverns, etc. Solution openings along vertical joints and bedding planes are more important from the point of their ground water yield. Concentrated vertical fractures provide zones of high permeability.

Shales:

Shales are the poorest aquifers. Although they are porous, they are impermeable. So, they are considered as Aquicludes. See the next chapter for the terms Aquifer etc.

CRYSTALLINE ROCKS:

Igneous and Metamorphic:

Igneous and metamorphic rocks are relatively impermeable, hence they serve as poor aquifers. Where such rocks occur near the surface under weathered conditions, they have been developed by small wells for domestic water supply. Acid granites are susceptible for weathering more rapidly than basic granites. If the top weathered layer is followed by fractured and jointed layer, below which hard rock occurs, weathered, fractured, and shear zone layers constitute potential zones of ground water.

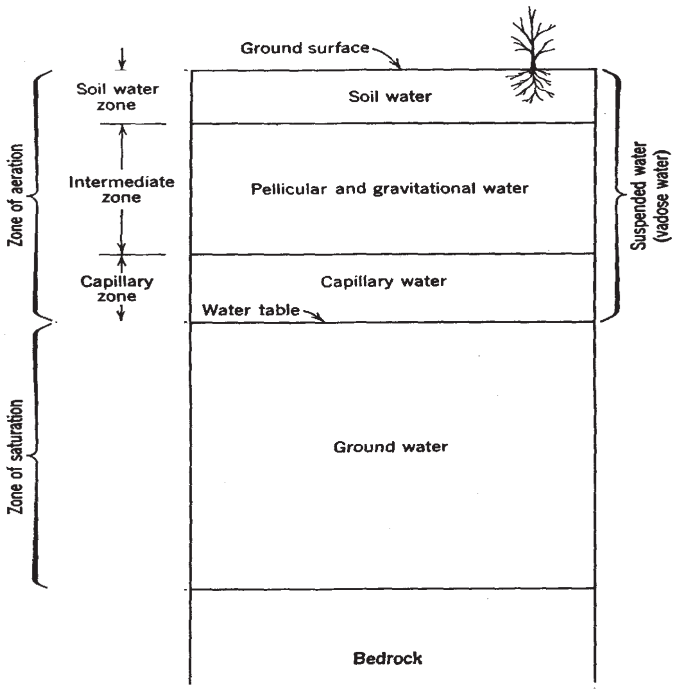
Volcanic rocks:

Volcanic rocks can form highly permeable aquifers. The openings in basalt such as vesicles, cavities between adjacent Lava beds, cooling cracks, fissures, and columnar joints etc. form as good aquifers.

VERTICAL DISTRIBUTION OF GROUND WATER

The subsurface occurrence of ground water is divided into the following zones.

i) Zone of Areation ii) Zone of Saturation



Divisions of Subsurface Water

The zone of aeration consists of interstices occupied partially by water and partially by air. In the zone of saturation all the interstices are filled with water under hydrostatic pressure. On most of the land masses of the earth a single zone of aeration overlies a single zone of saturation and extends upwards to the ground surface (as shown in the figure).

In the zone of aeration, vadose water occurs. The term vadose is derived from Latin 'vadosus' meaning shallow' . This zone may be further sub-divided into soil water zone, intermediate vadose water zone and capillary zone.

The saturated zone extends from the upper surface of saturation down to underlying impermeable rock. In the absence of overlying impermeable strata, the water table or phreatic surface forms the upper surface of the zone of saturation (phreatic= well). Water occurring in the zone of saturation is called 'Ground water' or ' Phreatic water'

ZONE OF AERATION:

Soil water zone:

Water in the soil water zone exists at the zone of saturation except temporarily when excessive water reaches the ground surface as from rainfall or irrigation. The zone extends from the ground surface down through the major root zone. Its thickness varies with the soil type and vegetation, because of the agricultural importance of soil water in supplying moisture to roots. Agricultural scientists and Soil Scientists have studied soil moisture distribution. The amount of water present in the soil water zone depends upon evaporation, climate and other factors.

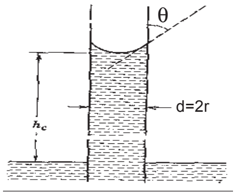
Intermediate zone:

The intermediate vadose zone lies in between soil water zone and capillary zone (as in figure). The thickness of this zone varies from 0 to more than 100 m. This zone serves as a region connecting the zone near ground surface with that near the water table . Through this zone excess water migrates downward as Gravitational water.

Capillary Zone:

This zone is also known as 'capillary fringe'. It extends from water table upto the limit of capillary rise of water. The phenomenon of water raising through the tubes of small dimensions against the force of gravity is called 'capillarity'. It is due to surface tension in water and adhesive forces exerted by the walls of the tube . The height to which water will rise in a uniform tubular opening is a function of the size of the tube and density of water. It is expressed by the following relation.

$$h_c = \frac{4\ T}{d\rho g}\ \mathrm{Cos}\theta$$



Where h_c is the capillary rise above the free water surface in cm, ‘T’ is the surface tension coefficient of the air water interface, ‘θ‘ is the angle of contact between the air water interface, and the wall of the capillary tube, ‘d’ is the diameter of the tube (in cm). ‘ρ’ is the density of water (in gm/c.c), ‘g’ is the gravity in N.

From the above expression, it will be found that height of the capillary rise of water in rocks is related to

i. *Dimensions of the voids*
ii. *Clean up of the walls of the interstices*
iii. *Temperature*
iv. *Mineral content of water on which density depends*
v. *Relative altitude of the rock where capillary phenomena are operative.*

If the rock formations are of sedimentary origin, the height of a capillary fringe depends upon the size of the grains and their sorting. In fractured rocks, the capillary fringe is determined by the size of the open joints and the size and sorting of the material filling up the joints.

Formation	*Capillary raise in Cm*
Gravel	*< 5 Cm*
Coarse Sand	*5-15 Cm*
Clay	*> 200 Cm*
Loam (Sand+Clay)	*150-200 Cm*

ZONE OF SATURATION:

In the zone of saturation, ground water fills all of the interstices. Hence, the porosity provides a direct measure of the water contained per unit volume. A portion of the water can be removed from subsurface strata by drainage or by pumping of a well. Molecular and surface tension forces hold the remaining water in place. This is a zone below which rocks are permanently saturated with water. Any well that penetrates this zone will contain water through the year.

Water Table:

The surface below which rocks are permanently saturated with water is known as 'water table '. The actual position of the water table shows seasonal variations. During the rainy season more water is added than is lost. So, water table rises and it will be very nearer to the surface. During summer more water is lost than is added. So, water table slowly sinks. Thus we can notice seasonal fluctuations in the positions of the water table. Water table itself is a surface. The surface is never flat. It is a subdued replica of the surface topography. Below the hills it is archedup, whereas below the valleys it is depressed. The reason is that the movement of ground water is so slow that there is no time to flatten out the water table before the addition of new supply from above. Directly as a result of uneveness of the water table surface, the ground water becomes mobile. The high areas in the water table tend to flatten out. Where, as the low areas tend to be filled in, if there is no addition of water, eventually, the water table will flatten out.

FORMS OF GROUNDWATER

Man brings somewater to the surface by means of wells, but much groundwater reaches the surface as a result of natural seepage, as in springs.

Wells:

A hole dug into the ground to a considerable depth which reaches the water table is called a well. If it is to be considered lasting forever, a well must be so deep that the water table will never be below its bottom, even during drought time. Wells should penetrate the zone of saturation and we should see that the wells donot become polluted.

Artesian wells:

The aquifer is a permeable bed and is overlain and underlain by impermeable (confining) beds. These realtionships cause a pressure head to exist, and the water stands higher near the recharge area. When a well is drilled into the aquifer, the pressure forces the water to rise above the aquifer. If the pressure is high enough, the well may be a flowing artesian well. The water tends to rise to the same level as the water table in the aquifer, as in a U-shaped tube, but friction prevents it from rising as high.

Springs:

A spring is developed when ground water comes to the surface and flows out more or less continuously

i. Hill side springs occur in hilly areas where the water table interescts the land surface.

ii. Fissure springs are naturally formed artesian wells, where the water reaches the surface through cracks or fissures in the rocks and comes out with considerable force.

iii. Hot springs or thermal springs contain water that has been warmed by contract with heated rocks in the subsurface Eg. Old Faithful in Yelow stone National Park in Wyoming in USA and Rotorua Spa in New Zealand.

iv. Mineral springs contain an unsually large qunatitites of dissolved salts such as NaCl, $KHCO_3$ and $MgSO_4$ and some times gases such as CO_2 or H_2S.

Geysers:

A geyser is a special type of thermal spring that intermittently erupts a column of steam and hot water. They originate in areas

i. Where ground temperatures are very high, and
ii. Where long narrow cracks are likely to be present in the rocks.

The ground water at the bottom of these cracks is heated to temperature far above the boiling point of water. The super heating of the bottom water is made possible because of pressure exerted by the water that lies above it. As a result, the water in the bottom of the crack expands and causes some of the overlying water to overflow on to the surface. This overflow relievs part of the pressure and allows the hot water to explode into stream, ejecting a great column of water in to the air.

Ex:- Old Faithfull Geyser in the Yellow stone National Park in America. It erupts columns of steam and water at intervals of (varying from) 60 min. It raises water to a height of 80m. Geysers are usually found in regions that have undergone recent volcanic activity and where there is still some magmatic activity at depth below the surface.

RECHARGE AND DISCHARGE AREAS:

Areas can be delineated into recharge and discharge areas depending on whether water in these areas is added to or abstracted from the zone of saturation. In the case of an unconfined aquifer, usually the areas occupying higher elevations with deeper water table constitute the recharge areas, whereas the topographic lows with shallow water table comprise natural discharge areas, between these two lies an intermediate transition zone characterised by extreme recharge conditions in some part of the year and discharge conditions in others. The boundaries keep changing, depending on the depth of the water table. In the case of an artesian aquifer, the recharge area is restricted to the out crop of the aquifer where it becomes uncontinued. If the confining layer is semipermeable, water may be supplied to or lost from the aquifer depending on the head differences

Ground water discharge areas are characterized by outcropping of the water table or the capillary fringe through which water is lost to the atmosphere by evaporation and transpiration or to steams as base flow. In general the outlets of ground water are diffused in the form of seepages, but at places, the flow may be directed in the form of springs through well-defined outlets.

UTILIZATION OF GROUND WATER:

Ground water is an important source of water supply throughout the world. Its use in irrigation, industries, municipalities or rural homes continues to increase. Cooling, air- conditioning have made heavy demands on ground water because of its characteristic uniformity in temperature.

Ground water is the primary water source in arid regions, and surface water in humid regions.

❏

Chapter 3

AQUIFERS

Definitions and Explanation with Figures

- **i. Aquifer**
    - **a. Unconfined Aquifer**
    - **b. Purched Aquifer**
    - **c. Confined Aquifer**
    - **d. Leaky Aquifer**
    - **e. Idealised Aquifer**
- **ii. Aquiclude**
- **iii. Aquifuge**
- **iv. Aquitard**

AQUIFERS

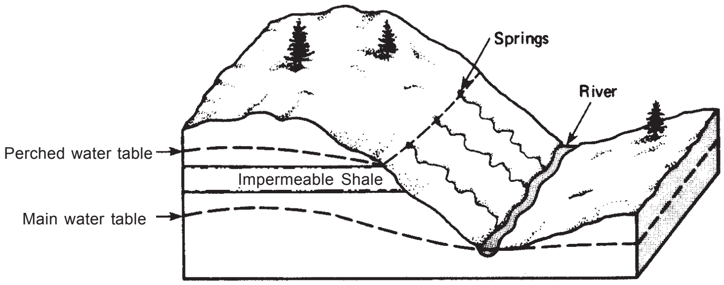
A geological formation that yields significant quantities of water is defined as an *Aquifer*. Ground water occurs in many types of geological formations known as Aquifers.

An aquifer may be defined as a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. This has an ability to store and to transmit water. Typical Example : Unconsolidated sands & gravels.

Ground water reservoir and water-bearing formations are the synonyms of aquifers. Aquifers are generally areally extensive and may be overlain and underlain by impermeable material called *confining bed.*

There are various types of confining beds.

Geological formations are classified on the basis of their water-bearing capacity which varies with their texture as follows:-



Perched Aquifer

AQUICLUDE:

A saturated but relatively impermeable material that doesn't yield appreciable quantities of water to wells. It has pores but is not permeable. Ex:clay

AQUIFUGE:

A relatively impermeable formation neither containing nor transmitting water. Rocks which are neither porous nor permeable. Ex: solid Granite, Basalt, etc.

AQUITARD:

A saturated but poorly permeable stratum that stops ground water movement and doesn't yield water freely to wells, but that may transmit appreciable water to or from adjacent aquifers. Where the formation is sufficiently thick it may constitute an important ground water storage zone. Ex:- sandy clay. Most aquifers are of large areal extent and may be visualized as underground storage reservoirs. Water enters a reservoir from natural or artificial recharge, it flows out under the action of gravity or it is extracted by wells.

TYPES OF AQUIFERS:

Aquifers vary in depth, lateral extent and thickness of the strata. They are classified as i. Unconfined aquifers ii. Confined aquifers depending upon the presence or absence of water table. Leaky aquifer represents a combination of the two types.

Unconfined Aquifer:

An unconfined aquifer is one in which water table varies in undulating form and in slope, depending on areas of recharge and discharge pumpage from wells and permeability. Rises and falls in the water table correspond to changes in the volume of water in storage within an aquifer.

Perched Aquifer:

A special case of an unconfined aquifer involves perched water body as shown in figure. This occurs whenever a ground water body is separated from the main ground water by a relatively impermeable stratum of small areal extent and by the zone of aeration above the main body of ground water. Clay lenses in sedimentary deposits often have shallow perched water bodies overlying them. These sources yield only temporary or small quantities of water.

Confined Aquifer:

Confined aquifers are also known as artesian aquifers or pressure aquifers. It occurs where ground water is confined under pressure greater than atmospheric pressure. If overlain and a relatively impermeable strata, in wells penetrating such an aquifer the water level will rise above the bottom of the confining bed,as shown by the artesian and flowing wells.

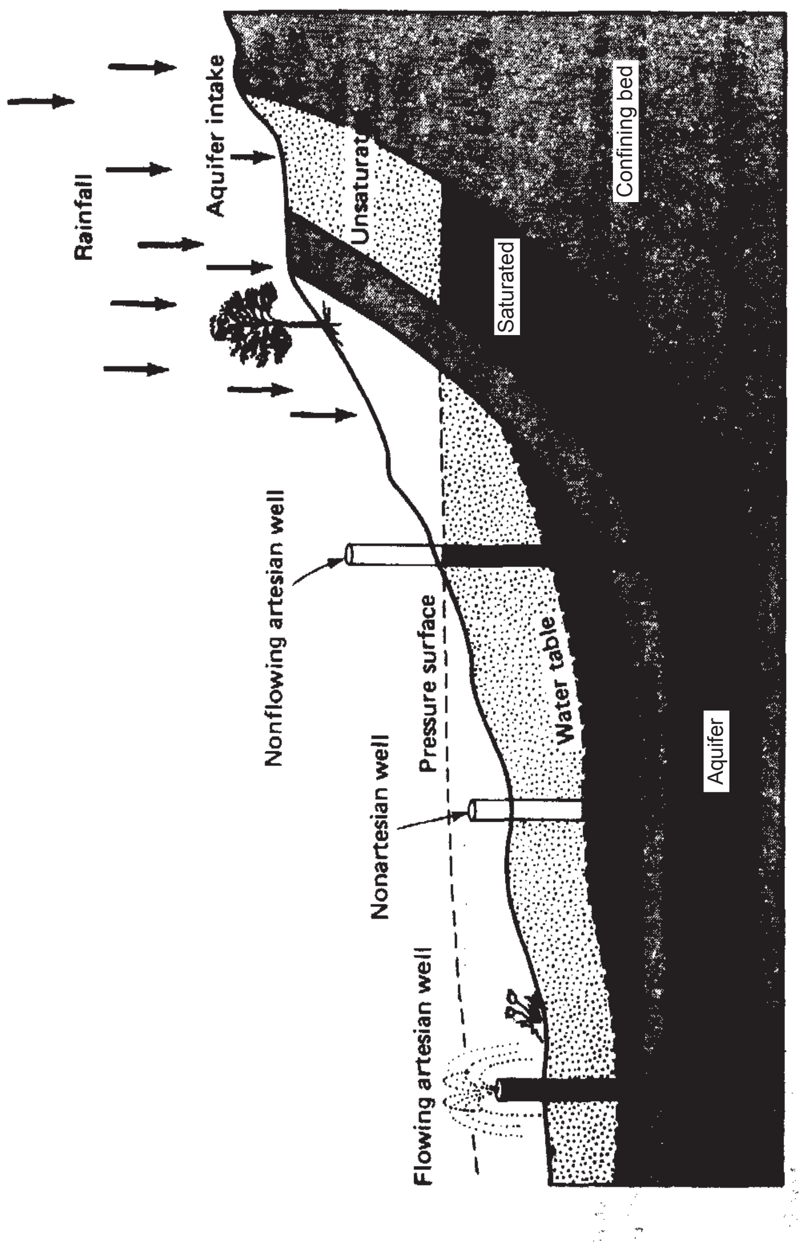
A region supplying water to a confined aquifer is known as Recharge area. Water may also enter by leakage through a confining bed. Rises and falls of water in wells penetrating confined aquifers results primarily from changes in pressure rather than changes in storage volume. Hence confined aquifers display only small changes in storage and serve primarily as conduits (passage or channel way) for conveying water from recharge areas to locations of natural or artificial discharge.

Leaky Aquifer:

Aquifers that are completely confined or unconfined occur less frequently than leaky aquifers. These are common features in alluvial valleys and plains, which form lake basins where a permeable stratum is overlain or underlain by a semipervious aquitard. Pumping from a well in a large aquifer removes water in two ways by horizontal flow within the Aquifer and by vertical flow through the aquitard into the aquifer.

Idealized Aquifer:

For mathematical calculations of the storage and flow of ground water, aquifers are frequently assumed to be homogeneous and isotropic. A homogeneous aquifer possesses hydrologic properties that are everywhere identical. An isotropic aquifer is one with its properties independent of direction. Such idealized aquifers do not exist.



Aquifer - Artesian System

❑

Chapter 4

WATER-BEARING AND WATER-YIELDING PROPERTIES OF ROCKS

Introduction
Porosity
Permeability
Darcy's Law
Specific Yield
Specific Retention

INTRODUCTION:

Some rocks are highly dense and devoid of interstices. Some other rocks are quite porous and can absorb water readily. Interstices in rocks have two functions, namely to store water(storage) and to allow water to pass through them(conduit). These two are dependent upon water-bearing, water-yielding & transmissive properties of the rocks. These properties differ in different rock formations and show diversity in origin, mineralogic composition, geological history and climate. Water-bearing, water-yielding properties of geological formations differ one from the other. The following are important water-bearing and water-yielding properties of rocks.

1. Porosity 2. Permeability 3. Hydraulic conductivity
4. Specific retension 5. Specific yield 6. Transmissibility

POROSITY:

It is defined as the ratio of the volume of voids in a rock mass to the total volume of the rock which is expressed in percentage.

If α is the porosity, V is the total volume of the rock and V_1 is the total volume of voids present in the rocks, then

$$\alpha = \frac{V_1}{V} \times 100$$

Effective Porosity:

The amount of interconnected space available for flow of water is called Effective Porosity. It is also expressed as the ratio of interstices to the total volume. Porosity present in rocks may be either primary or secondary. Primary porosity is that which is present in the rock right from its formation. Secondary porosity is that which is developed after the formation of rocks.

Primary Porosity:

Primary Porosity occurs as intergranular spaces in a sedimentary rock. It depends upon the size, shape and the arrangement of sediments. The degree of compaction and cementation of sediments are also the factors influencing porosity. In volcanic Igneous rocks, primary porosity is due to the vesicular structure. These vesicles may or may not be interconnected. From the Ground water point of view, these vesicles should be interconnected by fractures but not isolated. Among metamorphic rocks, foliation & lineation are responsible for little primary porosity.

Secondary Porosity:

Secondary Porosity occurs in rocks mainly in the form of 1.Joints 2. Faults 3.Shear Zones 4. Irregular Cracks 5. Solution openings in limestones 6.Openings of minor importance produced by the work of plants and animals and mechanical erosion. Secondary porosity may occur in all rocks due to weathering, (Desintegration and Decomposition). Weathering phenomenon produces a soil which is highly porous.

Factors Influencing Porosity:

(a) Porosity decreases with depth because density of rocks increases with the increase of depth. This is also because joints and cracks etc, decrease in number and magnitude with depth. Further, the weathering effect also decreases with increase of depth.

(b) The porosity of sediments depends upon the type of packing. If the fragments are subjected to cubic packing, its porosity is about 48%. On the other hand, if the same material has undergone rhombohedral packing, its porosity is about 26%.

(c) In unconsolidated sediments, the porosity is more when compared with consolidated rocks. This is because of the fact that in the consolidated sedimentary rocks cementing material decreases the porosity.

(d) Porosity also depends upon the rock texture.

i. Well-sorted sedimentary deposits have high porosity
ii. Unsorted sedimentary deposits have low porosity.
iii. In well-sorted sedimentary deposits, suppose the pebbles are also porous in addition to the intergranular pores, as a whole they have very high porosity.
iv. If the mineral matter is deposited in the intergranular space of the sediments, their porosity decreases.
v. In carbonate rocks the porosity is developed by solution action.
vi. Rocks which have been subjected to tectonic disturbances (tensile & compressive stresses), porosity is developed by fracturing.

(e) Porosity increases with the increase of grain size. Sediments of same shape exhibit low porosity, when compared with sediments of different shapes. Angular breceia may have higher porosity than rounded conglomerate.

(f) The average porosity values of some common geological formations are given below:-

Granite, Quartzite	*1.5%*
Slates, Shale	*4%*
Limestones	*5-10%*
Sandstones	*10-15%*
Sand with gravel	*20-30%*
Only gravel	*25%*
Only sand	*35%*
Clay	*45%*

(g) Rocks which do not have any porosity can't yield any ground water. Porosity in a rock provides not only space for the occurrence of ground water but also scope for its movement through the rock.

PERMEABILITY:

It is the ability of the rock to transmit water through it. A permeable rock always has high porosity, but a highly porous rock may not be permeable. Ex: Clay has a high porosity but low permeability. Sand has porosity less than clay but it is more highly permeable than clay. Permeability depends upon the following factors:

a. Size of open spaces:- Larger open spaces allow free flow of water. As the space becomes smaller, the permeability decreases. In clay the open spaces are so small that the surface tension effect causes the films of water to cling to the clay particles and make the water static. Moreover clay has the character of plasticity. Because of this property also its permeability decreases.

b. Interconnection between Open Spaces:- When the various open spaces are interconnected with each other, their permeability increases. Pore spaces and fractures which are not connected make the rock impermeable. Ex: Vesicular basalts are highly porous but less permeable due to the absence of interconnection between the vesicles.

c. Sorting of Grains:- Well-sorted sediments have a higher permeability than unsorted sediments. A uniformly coarse grained gravel has a higher permeability than the same rock consisting of fragments of different rock sizes.

d. Flow rate:- The flow of ground water through a porous medium is very slow. The flow rate of ground water varies from a few cms per year in rocks of low permeability to several cms per sec. in large passages of some caves.

DARCY’S LAW:

The movement of ground water depends upon the prevailing effects of gravity, velocity and pressures of water. Darcy's law may be defined as "The flow of water through a porous medium is proportional to a factor known as hydraulic gradient or hydraulic conductivity or coefficient permeability (K) which is characteristic of porous medium and cross-sectional area of an aquifer that is transmitting the water". This is expressed as $Q=KIA$

Using Darcy's law, what is the expected flow velocity V of water for clear sand 200 ft thick in a 1 mile wide valley? The sand has a K value of 500 ft per day and a water table slope of 5 ft./mi. The porosity of the sand is 20%. Note that 1 mile equals 5280 ft.

Solution: First, Solve for Q:

$$\begin{aligned} Q &= KIA \\ &= (500\text{ft/day})\ (5\text{ ft} / 5280\text{ ft})\ (200\text{ ft} \times 5280\text{ ft}) \\ &= 500{,}000\ \text{ft}^3/\text{day} \end{aligned}$$

Now solve for the average velocity of flow:

Since $Q = VA$, *then* $V = Q/A$

Because the actual flow is only through the area of voids (porosity) in the cross-section, then the velocity of flow through the sand is:

$$V = \frac{Q}{A \times \text{porosity}} = \frac{500{,}000\ \text{ft3/day}}{200\text{ ft} \times 5280\text{ ft} \times 20\%}$$

K=coefficient of permeability

Q=volume of water through a porous medium flowing per unit time through a cross-sectional area 'A' under a hydraulic gradient 'I'

Hydraulic gradient I measured by the difference in vertical elevation of water table between the two points divided by the distance between the two points.

Coefficient of Permeability:

From the above relationship it is clear that the volume of water flow depends upon the factor K. This K is defined as the "coefficient of Permeability. Coefficient of permeability is defined as the "ratio of flow water through a unit cross-sectional area of the aquifer of porous medium under a unit hydraulic gradient". Since Q/A gives the velocity of flow (V), it can be shown that the coefficient of permeability (K) expresses a velocity of flow for a unit hydraulic gradient (or) V=K when I=1. Coefficient of Permeability for some geological formations is as follows:

Geologic formation	*m/day(coeff,of permeability)*
Granite	*0.04*
Shale	*400*
Sand	*4000*
Sand and Gravel	*40000*
Gravel	*400000*
Clay	*0.04*
Lime stones	*4*
Slate	*4*
Quartzites	*0.04*

To estimate the reserve of ground water and its flow of a geological formation, 'K' value has to be determined separately because the value determined for one rock type at a given place is not applicable even to the same rock type at a different place. This means that permeability is not only a function of its porous medium but also of its geological environment.

Transmissibility:

Transmissibility literally means permeability. The coefficient of transmissibility (T) is defined as "the ratio of flow of water through a vertical strip of the aquifer of unit width and depth under a unit hydraulic gradient". The relation between T & K is as follows

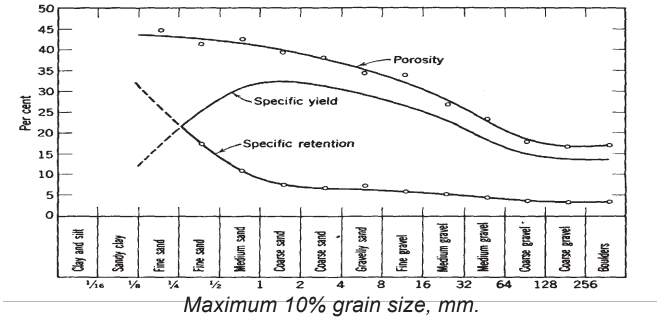
T=Kd, d=thickness of aquifer,
K=coefficient of permeability it is expressed in m^2/day.

SPECIFIC YIELD:

Porosity is a measure of the water-bearing capacity of the formation. All this water cannot be drained by gravity or by pumping from wells, since a portion of the water is held by the void spaces by molecular and surface-tension forces. The volume of water that can be drained by gravity (expressed as % of the total volume of the saturated aquifer) is called the Specific yield. It is denoted by S_y.

$$S_y = \frac{\text{Volume of water pumped out}}{\text{Total volume of the material drained}} \times 100$$

S_y = Porosity - Specific retention.



Porosity, specific yield and specific retention variations with grain size

SPECIFIC RETENTION:

The volume of water retained by molecular and surface tension forces against the forces of gravity, expressed as a percentage of the total volume of the saturated aquifer, is called specific retention. It is denoted by S_r.

$$S_r = \frac{\text{Volume of water held against gravity drainage}}{\text{Total volume of material drained}} \times 100$$

S_r = Porosity - Specific yield
Porosity = specific yield + specific retention.

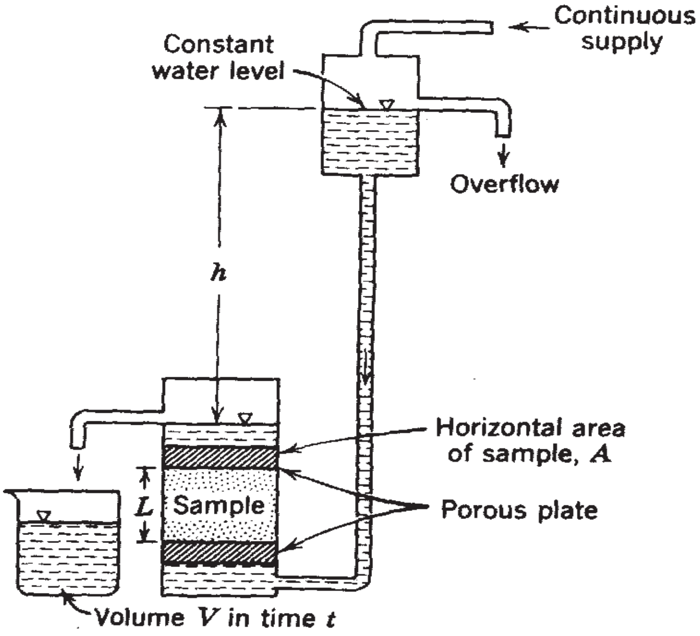
Measurement of Permeability:

In the laboratory, hydraulic conductivity or coefficient of permeability can be determined with the help of permeameters. There are two types of permeameters, namely, 1.Constant head permeameters

2.Falling head permeameters. Constant head permeameter is used for soil sample with high permeability. The falling head permeameters is used for soils with low permeability.

In the constant head permeameters the water flow is maintained through a small sample of material and the measurements of flow rates and head loss are made. The constant head permeameters can measure hydraulic conductivity of consolidated or unconsolidated formations under low heads. Water enters the middle cylinder from the bottom and it is collected as overflow after passing upwards through the sample. From Darcy's law it follows that hydraulic conductivity can be obtained from the given below equation

K = VL/Ath
L = length of the sample
A = Area of cross-section
h = height of constant water level
V = flow volume in time 't'.
Other dimensions are shown in fig.



Constant head permeameter

❑

Chapter 5

QUALITY OF GROUND WATER

Importance of Ground Water Quality
Physical Quality - Colour, Foam, Odour and Taste, & Turbidity,
Chemical Quality - p^H, EC, Hardness, Dissolved solids
Acidity and Alkalinity etc.
Calcium, Magnesium, Sodium, Potassium etc.
Carbonates, Bicarbonates, Chlorides,
Flourides, Nitrates, etc.,
Quality of Water for Domestic and Irrigation use.

IMPORTANCE OF GROUND WATER QUALITY:

In ground water resource evaluation, the quality of groundwater is equally important besides its quantity. The Physical, Chemical, Biological and Radiological Characteristics of groundwater determine its usefulness for domestic, industrial and agricultural purposes.The groundwater quality data gives important clues to the geological history of rocks and soils, indications of Groundwater recharge, discharge movement, storage and sources of pollution and other related aspects. A knowledge of water quality is also essential for management of water and land resources.

The following are different parameters of quality.

PHYSICAL	CHEMICAL	BIOLOGICAL
Colour *Foam* *Odour* *Taste* *Turbidity* *Temperature*	p^H *Electrical conductivity* *Acidity and Alkalinity* *T.D.S, Ca, Mg, Na,* *K, CO_3, HCO_3, SO_4* *Cl,NO_3,F, COD,BOD,* *Hardness etc.*	*Virus* *Bacteria* *Algae*
		RADIOLOGICAL *Uranium* *Thorium*

PHYSICAL QUALITY:

Physical quality of water includes Colour, Odour, Taste, Turbidity and Temperature.

Colour:-

Colour in ground water mainly results from the degradation in the natural environment. It may occur due to the presence of humic acids, fluvic acids, metallic ions such as Fe,Mn etc...., Suspended matter, industrial waste etc...,

Colour is expressed in terms of Hazan standard unit on Platinum cobalt scale. It is defined as the colour produced by 1mg/l of platinum in the form of chloro-platinic acid in the presence of 2 mg/l of Cobaltus chloride Hexahydrate.

Foam:

It is a suspension of gases or air bubbles in a liquid medium. Foams are caused by the presence of foaming substances such as synthetic detergents, soaps, proteins etc. Sometimes it traps pathogenic organisms.

Odour and Taste:

Odour and taste of water are mainly due to dissolved impurities often organic in nature. Odour may be of natural origin, caused by living and decaying aquatic organisms, accumulation of gases like Ammonia, H_2S etc.. Many algae also impart taste and odour to water. Sometimes reagents added to water supply system also produce odour and taste to water. Many inorganic chemicals are also capable of imparting taste. Eg:- NaCl - Salty; KCl, $MgCl_2$-Bitter etc. Tastes and odours in water are very important from the industrial point of view.

Turbidity:

Turbidity in water is caused by substances like clay, silt and organic matter. Turbidity makes the water unfit for domestic purposes and industrial purposes.

Temperature:

Generally groundwater temperature tends to remain constant when compared with surface water. Below the zone of surface influence, the ground water temperature increases approximately at the rate of 2.9°c for each 100 m depth in accordance with geothermal gradient of Earth's crust. Temperature must be measured immediately after collecting the water sample. It is basically important for its effect on the chemical and biological reactions of the organisms in water. A rise in temperature of the water leads to the speeding up of solubility of gases and changes the tastes and odours. Water in the temperature range of 7°to 11°c has a pleasant taste and is refreshing. At higher temperatures with less dissolved gases the water becomes tasteless.

Temperature is also important in the determination of various parameters such as p^H , conductivity, saturation level of gases and alkalinity. Data on temperature is also required by the industries in heat transmission calculations and other processes. 31.7 mts —1°c.

CHEMICAL QUALITY OF GROUND WATER:

Chemical analysis forms the basis of interpretations of quality of water in relation to source Geology, climate and use. Water being an excellent solvent, it is important to know the geochemistry of the dissolved solid constituents and methods of reporting analytical data. Analytical results are expressed in ppm. ppm=mg/l.

p^H:

The p^H value of a solution is the negative logarithm of the concentration of hydrogen ions in moles/litre at a given temperature. Dissolved gases such as CO_2, H_2S, NH_3 affect the p^H. The overall normal range of p^H of groundwater is 6-8.5. In natural water, p^H value ranges from 7-7.5. p^H is directly measured with the help of p^H meter. Groundwater polluted by mining activity, contains low p^H values (acidic)

Electrical Conductivity:

Conductivity is the measure of capacity of a substance to conduct electric current. It is the reciprocal of resistance. In water quality determinations, conductivity is defined as the conductance of a cube of 1cm side of a substance. It is reported in micro mhos/cm.

The specific conductance of groundwater varies widely. It increases with the increase of concentration of Total Dissolved Solids. This is a very important parameter which decides the usefulness of water for irrigation purpose. Electrical conductivity is determined with the help of conductivity meters.

Hardness:

This is a very important parameter which decides the usefulness of water for domestic purpose. A water which forms a residue with soap or when boiled, is termed as Hard. This property is due to the presence of alkali earth metal ions such as calcium and magnesium.

These constituents are found in groundwater mainly due to weathering of carbonate rocks leaving calcium and magnesium bicarbonates in solution. The hardness of water due to carbonates and bicarbonates of Ca and Mg is termed as temporary hardness. They can be removed by boiling. When the alkaline earth metal ions are derived from gypsiferous formation, the water will be enriched with sulphates and chlorides of Ca and Mg. The hardness thus resulting is not removable by boiling. It is known as Permanent hardness or Non-carbonate hardness. Highest desirable limit of hardness as $CaCo_3$ is 300 and maximum permissible limit is 600 ppm (according to ISI).

Total Dissolved Solids:

Total dissolved solids denote mainly various kinds of minerals present in water. In natural waters, dissolved solids are mainly composed of carbonates, bicarbonates, chlorides , sulphates, phosphates and nitrates of Ca, Mg, Na,K,Fe and Mn.

Concentration of dissolved solids is an important parameter in drinking water . They give a particular taste to the water at higher concentration and reduce its potability.

Concentration of T.D.S in water:

Excellent	*<300mg/l*	*0 - 1000 ppm*	*Fresh*
Good	*300-600mg/l*	*1000 - 10000 ppm*	*Brackish*
Fair	*600-900mg/l*	*10000 - 100000 ppm*	*Saline*
Poor	*900-1200mg/l*	*More than 1 Lakh ppm*	*Brine*
Unacceptable	*>1200mg/l*		

Acidity and Alkalinity:

Acidity of water is its capacity to neutralise strong base which is due to the presence of mineral acids. Ferrous Sulphate, Aluminium Sulphate etc., on hydrolysis produce strong acids and metal hydroxides. Metal hydroxides are soluble and produce acidity in water. In neutral water most of the acidity is present due to dissolution of CO_2 which forms Carbonic Acid. Excessive acidity in water causes corrosion and influences the chemical and biochemical reactions.

Alkalinity of water is a measure of its capacity to neutralise acids. Alkalinity of natural water is due to the salts of carbonate and bicarbonates and silica, etc. Alkalinity values provide guidance in applying proper doses of chemicals in water and waste water treatment processes. The ratio of alkalinity to that of alkaline earth metals is a good parameter in determining the suitability of irrigation water.

Calcium:

Calcium is one of the principal cations in groundwater. The main sources of Ca in groundwater are Pyroxenes, Amphiboles, Feldspars, Limestones, Dolomites, Gypsum etc., Since the solubility of igneous minerals is low, water from igneous and metamorphic rocks contains less calcium. In sedimentary rocks, Ca occurs as carbonate (Calcite, Aragonite, Dolomite etc.) Ca is extremely mobile in hydrosphere and common ion in subsurface water. The concentration of Ca in normal potable water ranges from 10-100 ppm. The desirable limit according to W.H.O standards is 75 ppm. But the maximum permissible limit is 200 ppm.

Magnesium :

Magnesium in groundwater is mainly derived from mafic minerals like Olivine, Augite, Hornblende, Talc, Serpentene etc., It is an important component of basic igneous rocks such as Dunites, Pyroxinites, Amphibolites, Volcanic rocks like Basalt and Sedimentary rocks like Dolomites. Common concentration of Mg ranges from 1-40 ppm. Water from rocks rich in Mg may have as much as 100 ppm. A high Mg content in groundwater in coastal areas indicates sea water contamination. Maximum permissible limit is 150 ppm.

Sodium:

Sodium is derived from feldspars in igneous rocks and its weathered products. Shale and clay layers often yield groundwater with high Na Content. The concentration of Sodium in groundwater varies from 1-50 ppm.Brines and salty waters occurring at great depths contain large amounts of Na. Groundwater in well-drained areas with good amount of rainfall usually contains less than 15 ppm of Na.

Potassium:

Common sources of potassium are the silicate minerals such as Orthoclase, Microcline, Leucite, Biotite etc., Evaporates containing highly soluble Sylvine KCl in some sedimentary rocks are another important source of K, however K levels in groundwater range from 10-15 ppm.

Carbonates and Bicarbonates:

The primary source of carbonate and bicarbonate ions in groundwater is the dissolved CO_2 in rain waters. It enters the soil and dissolves in groundwater. An increase in temperature or decrease in pressure causes reduction in solubility of CO_2 in water. Decay of organic matter may also release CO_2 for dissolution. Water charged with CO_2 dissolves carbonate minerals to give bicarbonates. Under usual conditions, the bicarbonate concentration in groundwater ranges from 100-800 ppm.

Sulphates:

Sulphate is formed by oxidation of pyrites and other sulphides widely distributed in igneous and sedimentary rocks. The most important sulphate deposits are found in evaporite sediments (Gypsum, Anhydrite etc.,)

In arid regions leaching of sulphates from the upper soil layers may also increase their concentration in groundwater. Hydrogen sulphide in excess of 5 ppm imparts offensive odour to the water. The highest permissible limit of sulphates is 200 ppm.

Chlorides:

Primary sources of chloride in groundwater are evaporites, salty connate water and marine water. Igneous rocks contribute little chloride.

Leaching of chloride from the upper soil layers may also cause high concentration in groundwater, particularly in arid regions. The recommended maximum concentration of chloride in drinking water is 250 ppm.

Fluorides:

The important fluorine-bearing minerals are Fluorite, Apatite, Amphiboles and Mica . The concentration of Fluorine in groundwater is limited due to the low solubility of most Fluorides. The solubility of Fluorine in pure water at 25°c is only 8.7 ppm. Mg fluoride is more soluble than Calcium fluoride. Sodium fluoride is very soluble.

Ground water in most areas contains less than 1.5 ppm of fluoride. Water with more than 1.5 ppm of fluoride can cause mottled teeth enamel in children. Excessive fluorides cause skeletal fluorosis in both children and adults. Eg:- People in some parts of Nalgonda and parts of Prakasam Dist. of A.P. are suffering from Fluorosis.

Nitrates:

Nitrates in groundwater are mainly derived from plants or sewage, nitrate fertilizers. A high nitrate content in groundwater indicates its pollution. Groundwater when not polluted contains less than 5 ppm of nitrates. But in polluted groundwater, the nitrate concentration may range upto 100 ppm or even more. (Desirable limit is 45 ppm)

Silica:

Silica is the most abundant in the Earth's crust. Most of the silica occurs in the groundwater as insoluble crystalline quartz. In water, silica is derived from the decompostiton of mineral silicates. Groundwater generally contains 1-30 ppm of silica and sometimes even upto 100 ppm. Silica has no effect on the hardness of water.

Iron:

Iron is one of the major metal ions of the Earth's crust. Important Iron-bearing minerals include Pyroxenes, Amphiboles, Micas among Silicates; pyrite and chalcopyrite among sulphates; magnetite and Haematite among oxides. Iron may be present in some sedimentary rocks in the form of cementing material. Iron may be acquired in solution by groundwater coming into contact with Iron objects such as well casings, delivery pipes etc.,

Iron occuring in groundwater is in the form of ferric hydroxide, in concentrations less than 0.5 ppm. Higher concentrations of Iron are attained by water with low p^H (acid water) and also by water from swamps and peat bogs.

QUALITY OF WATER FOR DOMESTIC USE:

Water for domestic use should be free from turbidity and should be colourless, odourless and tasteless. Harmful micro-organisms and radio activity must be absent. Most of the countries Like U.S.A. France and U.K have issued standards governing the quality of water for domestic use. In 1971 W.H.O . has laid down the following international standards for drinking water. According to them an excess of the following toxic constituents is dangerous to health.

Constituents	Maximum Allowable limit (mg/l or ppm)
Fluoride	*1.5*
Lead	*0.1*
Arsenic	*0.2*
Chromium	*0.05*
Cyanide	*0.01*
Nitrates	*45*
Selenium	*0.01*

The following limits govern the potability of water as excess can be generally distinguished by taste or odour. The permissible limits applied to water would be generally acceptable to consumers. Values greater than the desirable limit impair the potability of water.

Consitituents	Maximum Desirable (ppm)	Highest Permissible (ppm)
p^H	*7.85*	*6.5-9.2*
T.D.S	*500*	*1500*
Hardness	*<100*	*500*
Calcium	*75*	*200*
Magnesium	*50*	*150*
Sulphates	*200*	*400*
Chlorides	*200*	*600*
Iron	*0.3*	*1.5*
Manganese	*0.1*	*1*
Zinc	*5*	*15*
Nitrates	*45*	*45*
Copper	*1*	*1.5*

QUALITY OF WATER FOR IRRIGATION USE:

The suitablity of groundwater for irrigation use depends on the following: i) Electrical conductivity, ii) Sodium concentration, expressed in percent sodium, iii) Boron concentration. Wilcox's quality classification of water for irrigation with respect to the above parameters is given in the table.

Water Class	Per Cent Sodium	EC x 10^6 at 25°C	Boron, ppm Semitolerant Crop
Excellent	*<20*	*<250*	*<0.67*
Good	*20-40*	*250-750*	*0.67-1.33*
Permissible	*40-60*	*750-2000*	*1.33-2.00*
Doubtful	*60-80*	*2000-3000*	*2.00-2.50*
Unsuitable	*>80*	*> 3000*	*> 2.50*

Wilcox's Quality Classification of Water for Irrigation

In classifying the water for Irrigation use, sodium concentration is important because Sodium reacts with soil to reduce its permeability. Soils which contain Sodium carbonate are termed as Alkali soils, whereas soils which contain either Sodium sulphate or Sodium chloride, are known as Saline soils. Both Saline and Alkali soils hamper the growth of plants.

In very small quantities, Boron is essential for normal growth of plants, but in high concentrations it becomes toxic.

❑

Chapter 6

POLLUTION OF GROUNDWATER

Definition

Causes and Sources of Pollution

- **i. Domestic and Urban Pollution**
- **ii. Agricultural Pollution**
- **iii. Industrial Pollution**
- **iv. Other causes**

DEFINITION:

Pollution is a modification of the physical, chemical and biological properties of water, preventing its normal use in various applications. Ground water pollution is defined as the degradation of natural quality of ground water, which results in an undesirable change in its quality. A pollutant is a substance which affects and alters the quality of water. Pollutants are introduced into the environment in significant amounts from various sources. There are two broad sources, namely:

Point Source:

Point source can be traced and the specific location of the source of pollution can be identified.

Non-point Source:

Non-point source cannot be traced in this case, since it is multi-dimensional (Varied nature). Eg: Agricultural pollution.

CAUSES AND SOURCES OF POLLUTION:

A large number of sources and causes can modify the quality of ground water. They are classified and described below:

i. Domestic and Urban Pollution. ii. Agricultural Pollution
iii. Industrial pollution. iv. Other causes.

DOMESTIC AND URBAN POLLUTION:

Sewer leakage :

Sanitary sewers are intended to be watertight. But in reality, leakage of sewage into the ground commonly occurs. Leakage is resulted due to poor workmanship, defective sewer pipe, breakage by tree roots, ruptures from heavy loads, fractures from seismic activity etc.

Due to the sewer leakage, high concentrations of B.O.D., C.O.D., Nitrates, Organic chemicals and Bacteria are introduced into the ground water.

Liquid waste :

Waste water in urban areas originate from domestic source and industries, such water without giving treatment is discharged into the surface water and finally finds way into the ground water causing pollution.

Solid waste:

Land disposal of solid waste creates an important source of ground water pollution. Urban or municipal solid waste is deposited over a land called land-fill. If water moves through such a land-fill, it pollutes ground water. The problem of pollution from land-fills is the greatest where high rainfall and shallow water table occur. Important pollutants are B.O.D, C.O.D, Iron, Manganese, Nitrates etc. Due to that Hardness, Alkalinity and T.D.S are also increased.

Septic tanks and cess pools:

In urban and highly populated domestic areas leakages from septic tanks and cess pools cause ground water pollution on a larger scale. Significant quantities of Nitrates can be added to Ground water.

Roadways Deicing salts:

Chloride ions from runoff from road deicing salts cause high chlorinity in ground water. High chlorinity tends to corrosion of wells.

AGRICULTURAL POLLUTION:

In Agriculturally developed and developing countries like India, Ground water is being polluted due to Agricultural sources derived from Fertilizers, Irrigation salts, Animal waste, Crop waste disposal, Pesticides and Herbicides etc..

Irrigation Return Flows:

Approximately ½-2/3 water applied for irrigation of crops is consumed by Evapo - transpiration. The remaining is termed as irrigation return flows which drain surface channels and meet the underlying water. With the increase of irrigation, salinity of soils also increases in some regions. This also causes Ground water pollution because Meteoric water has to percolate through the soil layers. Soil pollution is more in black soil regions because of their water retaining capacity and less drained nature.

Animal waste :

Where animals are confined within a limited area for beef or milch production, large amount of animal wastes are deposited on the ground. Stream runoff in contact with the manure carries highly concentrated pollutants to the sub-surface waters. Animal waste may transport salts, organic loads and bacteria into the soil. Nitrates are the most important pollutants which reach the water table.

Fertilizers and soil Amendments:

When fertilizers are applied to the agricultural land, a portion usually reaches through the soil and to the water table . The primary fertilizers are compounds of NPK. Phosphate and potash fertilizers are absorbed by the soil particles and nitrogen is the primary fertilizer pollutant.

Soil amendments are applied to irrigated lands to alter the physical or chemical properties of the soil. Lime, Gypsum and Sulphur are used for this purpose.Excessive amounts of these soil amendments are leached into the ground water and increase salinity. Eg:- Excessive application of Nitrogen fertilizers in Badshapur, Mirjhapur and Hamirpur regions of U.P lead to the ground water pollution. This has resulted in blue coloring of the skin and also Goiter.

Pesticides and Herbicides :

Insecticides, Pesticides and Herbicides are cumulative poisons in agricultural areas and cause ground water pollution. The impact of pesticides on the ground water quality depends upon the properties of pesticide residue, rainfall or irrigation rates and soil characteristics.

INDUSTRIAL POLLUTION:

With the increase of innumerable industries all over the world, the rate of pollution is also increasing alarmingly. The following are different sources of industrial pollution.

Liquid waste:

The major use of water in Industrial plants is for cooling , sanitation, manufacturing of different products and processing. The quality of the waste water varies with the type of industry and type of use. Ground water pollution can occur where industrial waste waters are discharged without secondary treatment into pits, ponds or lagoons and ultimately migrate down to the water table.

Eg: i) Industrial effluence containing high concentrations of Chromium, Lead, Arsenic and Tin have infiltered into aquifers in the areas where wools are dyed in Ludhiana district of Punjab.

ii) N.F.C.(Nuclear fuel complex) of Hyderabad is responsible for the rise of nitrates in ground water to the extent of 440 ppm against the permissible limit of 50 ppm.

Tank and pipe line leakage:-

Petroleum tanks and pipe lines of chemicals when subjected to structural failure, cause ground water pollution due to leakage. Eg:- Gasoline pollution in ground water occurred in California.

Mining Activities:

Mines can produce a variety of ground water pollution problems. Pollution in this case depends upon the material being extracted and the milling process. Coal, Phosphate and Uranium mines are major contributors of ground water pollution. Metallic ores for the production of Iron, Copper, Zinc and Lead etc. are also creating pollution problems. Both surface mines and underground mines extend below the water table so that dewatering to expand mining is common, water so pumped out is highly mineralised which is known as Acid Mine discharge. Such waters have low p^H, high iron and Aluminum and phosphate. Coal deposits are often associated with Pyrite, oxidation of pyrites followed by contact with water produces ferrous sulphate and sulphuric acid. Such a ground water has low p^H and high iron and sulphate. Pollution of ground water can also result from the leaching of mineral matter from both active and closed mines. Radiological pollution occurs in the Uranium and Thorium mining areas.

Oil field brines:-

The production of oil and gas is usually accompanied by the discharge of waste water in the form of brine.Sodium, Calcium, Ammonia, Chlorides, Boron,Sulphates and high T.D.S. are the constituents of the brine in oil production areas. The infiltering polluted water from the brine reaches the ground water and causes pollution.

Trace- Metal pollution:

In industrial areas heavy metals such as Arsenic,Cobalt, Cadmium, Chromium, Copper, Lead, Iron, Manganese and Mercury enter into the waste water as traces, and finally reach the ground water table to cause pollution.

Spills and surface Discharges:

Liquids discharged on the ground surface in an uncontrolled manner can migrate downward to degrade groundwater quality. At industrial sites casual activities may include boil overs, losses during transfers of liquid leaks from pipes and valves. Washing aircrafts with solvents and spills of fuel at airport can form a layer of hydrocarbons floating on the water table. Pollution can also occur due to dumping of fluids on the ground, especially near gasoline stations, small commercial establishmentns and constructon sites.

Stock Piles:

Solid materials are frequently stock piled near industrial plants, construction sites and large agricultural operations. Precipitaion falling on unsheltered stock piles causes leaching to occur into the soil. This may transport heavy metals, salts and other inorganic and organic constituents as pollutants to the groundwater.

Other Causes:

i. Pollution from salt water intrusion.
ii. Pollution from surface water contamination.
iii. Pollution from wells.
iv. Pollution from atmospheric dissolved gases.
v. Pollution from radioactive substances.
vi. High concentrations of fluorine, etc.

Saline water intrusion into the Groundwater is the common problem in the coastal areas by sea.

For surface water contamination Groundwater near Moosi river bank (Hyderabad) is the best example. There ground water is polluted due to disposal of domestic and industrial waste.

Chapter 7

EXPLORATION OF GROUNDWATER

Introduction
Hydrogeological Exploration
  i. Geological Investigations
  ii. Hydrological Investigations
Geophysical Exploration
  i. Gravity method
  ii. Magnetic method
  iii. Seismic method
  iv. Electrical Resistivity method

INTRODUCTION:

Groundwater does not occur everywhere below the Earth's surface. Its occurrence below surface is not meant for direct observation. Hence suitable studies are necessary to make the attempts of tapping groundwater successful. The scientific approach in groundwater exploration includes.

Hydrogeological Exploration
  i. Geological investigations
  ii. Hydrological investigations

Geophysical Exploration
  i. Gravity method
  ii. Magnetic method
  iii. Seismic method
  iv. Electrical Resistivity method

GEOLOGICAL INVESTIGATION:

In groundwater exploration, among the three kinds of investigations, geological investigation is the most important and the main deciding factor. The other two provide supplementary information. Geological investigation comprises the study of a given area from different angles to predict the scope of ground water occurrence there.

Study of lithology :

This refers to not only the outcrops of rock types occurring but also to their thickness, altitude (i.e strike and dip details) and their porosity and permeability characters. Altitude of rocks i.e. dip direction of bedding planes influences the flow of groundwater beneath the surface.

Study of Topography :

This refers to the occurrence of high lands such as hills, and low lands such as valleys. The water table will be roughly parallel to the surface i.e. occurring at a relatively higher level in hilly regions and at a depth below valleys in low lands . But its rise or fall is always gentle. Further, groundwater flows from places with a higher water table level to places with a lower water table level. In groundwater exploration, places of the lower elevation are preferred because

i. The depth of actual occurrence of water table will be relatively less than in hilly regions and
ii. Ground water comes from different sides to that point.

Study of weathering:

In hard rock areas, surface occurrence of *insitu* rocks as base boulders without soil and subsoil zones is not suitable for tapping groundwater because they not only lack weathered zones but also joints and fractures which may occur on the surface shall become less prominent and disappear at a depth. This means porosity will be less and hence there is no scope for occurrence of plenty of groundwater. On the other hand, the valleys and low lying places are suitable for groundwater tapping because they are not only the places of natural deposition of sediments (due to the action of different geological agents) but also they are the places where the weathering of *insitu* rocks would have occurred more for various reasons. Low lying places have also the advantages.

Study of geological Structures:

This refers to the trend or altitude of joints, cracks, faults, shear zones, folds etc. which not only contribute to secondary porosity but also act as channel ways or guide the directions of movement of ground water. Syclinal folding accompanying suitable lithology leads to artesian conditions which are very much sought after in ground water exploration because they generally yield a copious supply of water.

Remote sensing and aerial photographs:

Photographs of the earth taken from air-craft or satellite at various electro-magnetic wavelength ranges can provide useful information regarding ground water conditions of a region.

Stereoscopic examination of black & white aerial photographs has gained importance since observable patterns, colors and relief make it possible to distinguish differences in geology, soils, soil moisture, drainage, vegetation and land use. Thus photogeology can differentiate between rock and soil types and indicate their permeability and aerial distribution and hence areas of ground water recharge and discharge. Maps classifying an area into good, fair, and poor ground water yields can be prepared. Aerial photographs also reveal fracture patterns in rocks, which can be related to porosity, permeability and ultimately well yield. Springs and marshy areas indicate relatively shallow depths to ground water.

Hydrogeobotanical Prospecting:

Hydrobotanical studies of vegetation in photographs can be productive. Phreatophytes (water loving), which transpire water from shallow water tables, define depths to ground water. They are good indicators of ground water. Halophytes, plants with a high tolerance for soluble salts and white efforescences of salt at ground surface indicate the presence of shallow brackish or saline ground water. Xerophytes (plants grow in dry conditions and commonly occur in arid regions) desert plants subsisting on mineral water suggest a considerable depth to the water table.

The following surface features can be identified with the help of aerial photographs. They are of immense use in assessing the occurrence of ground water in a region.

i. *Topography*
ii. *phreatophytes and aquatic plants*
iii. *Geologic land forms like alluvial fans, valley fills, flood plains etc.*
iv. *Surface water bodies such as lakes, springs etc.*
v. *Moist depressions and seepages*
vi. *Artificial water features such as reservoirs, wells, canal systems, tanks etc.*

Infrared imagery, which records differences in apparent surface temperatures, enable information on soil moisture, ground water circulation and faults. Radar imagery provides information on the presence of moisture at shallow depths below ground surface. Low frequency electro-magnetic aerial surveys have outlined burried channels and zones of sea-water intrusion.

Study of intrusive rocks:

This refers to the occurrence, trend and extent of dolerite dykes, quartz veins, etc., These being hard and resistant may act as barriers to the normal flow of ground water. This results in the accumulation of ground water on one side of the intrusive only. Thus, it is a common experience that in some places ground water may be plenty in a particular area and may be scarce in a nearby area.

Geological mapping:

This reveals most of the foregoing field data and hence is very important. In this, the actual mode of occurrence of rocks along with the associate geological structures and intrusive are shown over the contour map of that area.

HYDROLOGICAL INVESTIGATIONS

Such investigations are relatively simple but very important in the assessment of ground water potentiality in any region. While selecting a site for any structure the directional trend of flowlines and other hydrologial features shoult not be ignored under any circumstances.

Study of the water table:

In any region, the observations and estimation of the depth of the static water level in a number of wells and bore wells offer valuable informations about the relative position, the nature of the slope of the water table and the probable direction of flow of ground water (which is dependent on the hydraulic gradient) in the area concerned. If more details of this kind (i.e., static water levels in many wells) are available, it is possible to represent the regional water table in the form of a contour map and thereby visualize an exact and distinct picture of the existing ground water conditions.

Study of surface water bodies:

This refers to the occurrence of networks of streams, ponds, lakes, reservoirs etc. in the area. Their presence is desirable because they act as sources of percolation or recharge of ground water.

Study of springs and seepages:

If natural seepages and springs occur in an area, this indicates a high water table position and rich ground water conditions. Any alignment of springs indicates faults. Faults contribute to rich ground water occurrence.

Quality of water:

It is necessary to know, whether ground water is potable. Water drawn from granites tastes good normally, but when water is drawn from dolerite it is brackish. Groundwater drawn from pegmatitic rocks which are rich in flourinated minerals like apatite and mica etc., causes health problems such as Fluorisis.

Study of rainfall, climate etc.:

These details are of a suggestive nature, (i.e.,) regions having good rainfall and a humid climate will have good ground water potential and natural regions with a little rainfall and arid climate will have low ground water potential. Ex: Anantapur district of Andhra Pradesh has low ground water potential.

Pumping tests:

These are very important to know the yield characteristics of the aquifer concerned. The rates of draw down recorded during pumping reveal this information.

GEOPHYSICAL EXPLORATION

Geophysical exploration is the scientific measurement of physical properties of the Earth's crust for investigation of mineral deposits, geological structures or ground water resources. Organisations concerned with ground water employ geophysical methods. They are most useful when supplemented by Surface investigations. Geophysical methods detect differences or anomalies of physical properties within the Earth's crust. Density, magnetism, Elasticity and Electrical conductivity and Resistivity are the properties most commonly measured. Differences in these properties are interpreted in terms of geologic structures, rock type and porosity, water content and water quality. Depending on the physical principle employed, the following types of geophysical methods for prospecting ground water are applied.

GRAVITY METHOD:

Gravity methods represent a set of geophysical methods which make use of the natural gravity field of the Earth.

Physical Property: Density

Principle:

In gravity methods, the nature of distribution of gravity, *g* on the surface is analysed. The gravity is influenced positively if the causative body is heavier, larger and occurs at a shallow depth. Thus, in a particular region, if subsurface bodies (such as ore deposits, coal seams and salt domes) whose densities are different from the surrounding rocks exist, the gravity field deviates from the normal value that is expected if the heterogeneities are not present. From these deviations, it is possible to locate the heterogenous bodies in the subsurface. In the waterbearing zone, density is less.

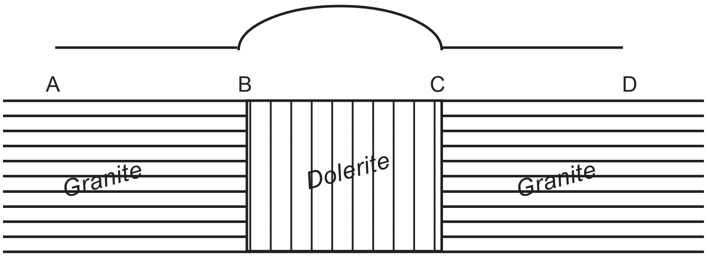
MAGNETIC METHOD:

This method takes the advantage of the natural magnetic field associated with the Earth (geomagnetic field) and its relation to subsurface geology.

Controlling Property: Magnetic Susceptibility

Principle:

The magnetic methods are based on the fact that the magnetic bodies present in the Earth's subsurface contribute to the magnetic field of the Earth. As in the gravity methods, the contribution of the magnetic body is directly proportional to the magnetic moment of the body and its size, and is inversely proportional to the depth of its occurrence. In general, when the magnetic field of the Earth or one of its components (either vertical or horizontal component) is measured on the surface bodies possessing magnetic moments different from those of the surrounding rocks contribute to the deviations in the measured quantities. From these magnetic anomalies it is possible to locate the anomalous objects. In the water bearing zone the magnetic susceptibility is low. The following figure explains this aspect.



SEISMIC METHOD:

Seismic method of prospecting is carried out by making use of Elastic property [seismic wave velocity].

Principle:

Seismic methods of studying are based on the principle that the subsurface rock formations bear different elastic properties. Because of this, the velocities of propagation of seismic waves through them change with changes in Lithology. Measurement of seismic wavevelocities of rock formations provide a scope to distinguish different subsurface lithological units. In seismic methods, artificial explosions are made in the ground. The seismic waves thus produced travel through the subsurface layers of the earth, suffer reflection or critical refraction and arrive at the surface of the Earth where they are detected by geophones. From the time taken by the waves to travel, through the subsurface formations and from the seismic wave velocities of the media it is possible to determine the depths on various elastic boundaries. Seismic prospecting are the most complicated and expensive. In the water-bearing zone, the seismic wave velocity is high.

ELECTRICAL RESISTIVITY METHODS:

Introduction:

Electrical Resistivity Method is an important and useful geophysical method to investigate the nature of subsurface formations by studying the variations in their electrical properties. This method assumed considerable importance in the field of ground water exploration because of its ease of operation, low cost and its capability to distinguish between the saline and fresh water zones.

Resistivity:

Resistivity is a physical property of a substance (like density). It is an inherent property of the substance and is independent of size and shape of the substance. The *Resistivity* is defined as the resistance offered by a unit cube of a substance to the flow of electric current when the voltage is applied at the opposite faces of the cube.

$$R = \frac{\rho L}{A} \quad ==> \quad \rho = \frac{RA}{L}$$

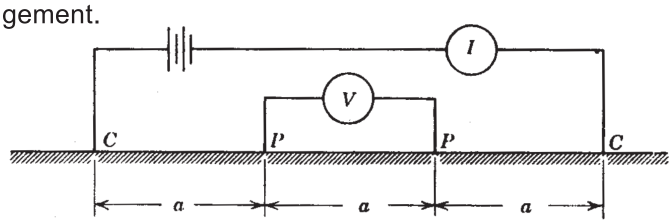
Where

R = Resistance offered by the substance
A = Cross sectional area of the substance
L = Length of the substance
ρ = Resistivity of the substance, Ohm-m is the unit of resistavity

Acutal resistivities are determined from apparent resistivities which are calculated from measurements of current and potential differences between pairs of electrodes placed in ground surface.

The equipment is simple consisting essentially of i) a source of electrical power (battery or generator) ii) electrodes and connecting wires. iii) ammemeter and voltmeter

The following figure shows the position of electrodes of Wenner arrangement.



Common electrode arrangements for resistivity determination
Wenner Method

The voltages are usually measured in potentiometric arrangements so that current flow in the measuring circuit does not produce distortions.The depth of the current penetration depends on i) The geometry of disposition of electrodes. ii) The frequency used, and iii) Conductivity distribution.

Resistivities of Different Rock formations:

i. Resistivity of rock formations depends upon the material density, porosity, pore size and shape, water content and quality, temperature.

ii. There are no fixed limits for resistivities of various rocks.

iii. In igneous and metamorphic rocks,the resistivities range from 10^2 to 10^8 ohm-m.

iv. In sedimentary and unconsolidated rocks the resistivities range from 10^0-10^4 ohm-m.

v. In relatively porous formations, the resistivity is controlled more by water content and quality within the formation than by the rock resistivity.

vi. For aquifers composed of unconsolidated materials the resistivity decreases with the degree of saturation and the salinity of ground water.

vii. Clay minerals conduct electric current through their matrix. Therefore clay formations display lower resistivities than permeable alluvial aquifers.

viii. The correlation of the interpreted results of geophysical soundings indicate the favourable ranges of resistivities, as 50-200 ohm-m in Cuddapahs; 40-150 ohm-m in Crystallines; 50-60 ohm-m in Sandstones; 60-80 ohm-m in alluvium and 2-10 ohm-m in Clays.

❑

Chapter 8

ARTIFICIAL RECHARGE OF GROUNDWATER

Introduction
Spreading Methods
Flooding Method
Irrigation Method
Pit Method
Recharge Well Method
Watershed
Definition
Hydrogeological Significance

INTRODUCTION:

Ground water is a renewable resource hidden beneath the surface of the earth. The infiltrated and percolated waters through this soil cover occupy the interstices or openings, fractures and joints of the lithological units and thus accumulate as ground water reservoirs. This process is called natural Recharge of ground water from precipitation during the hydrologic cycle.

But in the case of artificial recharge, water is managed to get infiltrated and percolated into the ground to reach ground water body by the methods of spreading and flooding of water.

All the seepage effect from the surface water body may be taken as the artificial recharge of ground water. During this process additional reserves are added to the ground water body for the augmentation of water supply and also to safeguard the decline of water table. Artificial Recharge may be accomplished by a variety of methods. The widely practiced method is the water spreading, releasing the water over the ground so as to facilitate to infiltrate into the ground and percolate to reach the ground water body as additive reserves.

SPREADING METHODS:

Basin method:- Water may be recharged by releasing it into basins formed by excavation.

Stream channel method:

Water spreading in a natural stream channel involves operations that increase the time and area over which water is recharged. This involves both upstream management of stream flow, and channel modification to enhance infiltration.

Ditch and furrow methods:

In this method water is distributed to a series of ditches or furrows which are shallow and flat-bottomed.

FLOODING METHOD:

In relatively flat topography water may be diverted to spread evenly over a large area.In practice canals and gullies are usually required to release the water at intervals over the upper end of the flooding area.

IRRIGATION METHOD:

In an irrigated area, water spread by irrigation crop land with excess water keeping irrigation channels full will contribute to recharge by seepage from the canals.

PIT METHOD:

A pit excavated into a permeable formation serves as an ideal facility for ground water recharge. These pits may be called recharge pits.

RECHARGE WELL METHOD:

A recharge well may be defined as a well that admits water from the surface to fresh water aquifers. Its flow is the reverse of pumping.

Incidental or unplanned recharge occurs when water enters the ground as a result of human activity - Irrigation channels, canals, and reservoirs, etc. In most of the cases polluted waters are introduced.

Waste water recharge for reuse:

In recent years municipal waste waters are reused after secondary treatment. Recharge of such waters improves its quality by removal of physical, biological and chemical constituents. At present the watershed management in river basin is more effective and encouraging in administering the artificial recharge of ground water.

WATERSHED:

Watershed may be defined as a Physiographic unit having definite boundaries within which the precipitated water will be drained towards the common channels and let out through single or limited outlets.

HYDROGEOLOGICAL SIGNIFICANCE:

The Watershed management has got significant effect in emeleorating artificial recharge of Ground water so as to facilitate to augment the water supply. Normally the catchment of drainage basin in upland areas are at higher relief with steep gradients that facilitate splash runoff. This leads to soil erosion in large quantities. In order to retard the velocity of run off and soil erosion, watershed management may be taken up by proper treatment of area under different aspects. In a properly treated area of watershed, the velocity of runoff is arrested and facilitated to infiltrate into the ground water by adding the additional reserves to ground water body for futher augmentation. In over-exploited areas also which are categorised as Gray (draft between 65 and 85 % of reserves) and Dark (more than 85%), the Watershed management is the immediate treatment which functions as remedial measure and restores the ground water body safeguarding from fluctuations and total depletion.

Further, its replinishment effect may reverse the Gray and Dark area features to that of White area (draft less than 65%) which is a safe and desirable condition for the practical utilitarian aspect of Ground Water.

❑

Chapter 9

SEA-WATER INTRUSION

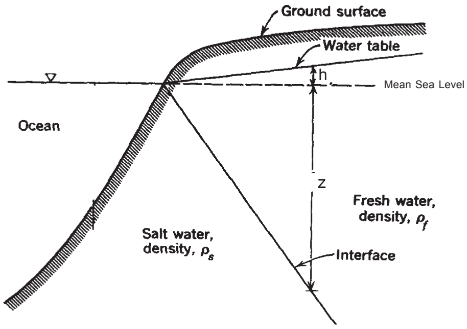
Definition & Description
Figure & Examples

DEFINITION:

The sea-water intrusion may be defined as an entry or encroachment of sea-water into the coastal aquifers, when the discharge of ground water into the oceans is decreased due to known reasons. The contact surface in between the fresh and saline waters is known as *interface.*

In coastal aquifers sea-water intrusion is the major problem of polluting ground water rendering it unfit for the purpose of irrigation. Along the coastal line the fresh and salt water maintain an equilibrium because of the differences in density.

This is vividly studied by two German scientists, namely Ghyben



Sketch of fresh and slat-water distributions in an unconfined coastal aquifer to illustrate the Ghyben-Herzberg relation.
$z = 40h$

and Herzberg and established the concept of fresh and salt water interface in coastal aquifers. The experiment is based on the density relationship of salt and fresh water in which the density is higher in the case of the former and lower in the case of the latter. Hence the fresh water floats on the salt water and its accumulation will be 40 times the water table on the salt water. If the drawal is more, the salt-water intrudes in land due to disturbance of the equilibrium along interface.

Examples of sea-water intrusion:

1. Lanka areas such as Potharlanka in Tippacatla village of Repalle Taluq, Guntur District.
2. Padarthi,Tangutur, S.Konda areas of Prakasam District.
3. Duggaraju Patnam of Vakadu Mandal of Nellore District.

It is always advisable to avoid such disturbances of the equilibrium of fresh and salt water along coastal line. When once intruded it is not at all possible to push it back by artificial means as sea is the major body of water intruding inland on large scale. While utilizing the ground water appropriate number of structures are to be suggested based on the availability of the fresh water reserves. Heavy pumping with higher H.P of pump sets should not be done because of disturbance of the equilibrium. Appropriate pump sets are to be suggested for the drawal of fresh water. In some cases it is possible to bail out fresh water in certain period and later salt water is encountered during pumping. In such cases the constant period of pumping of fresh water may be established by conducting tests, and utilization has to be done only based on the permissible period of fresh water drawal.

Mixed water management may be administered depending upon the availability of the fresh water in the vicinity of the area along coastal line.

Further, injection wells at favourable sites may be located to avoid decline of water table by injecting the fresh water from the nearby sources so as to maintain the steady status of fresh salt water interface. This method not only safeguards the decline of water table from the disturbance but also avoids sea-water intrusion.

Hence precautionary methods are of paramount importance in safe-guarding the fresh ground water from sea-water intrusion along the coastal line.

❑

Chapter 10

MANAGEMENT OF GROUNDWATER

Introduction
Definition of Groundwater Basin
Concept of Basin Management
Basin Investigations
Alternative Basin Yields

INTRODUCTION:

The Management of ground water involves its utility in the field of practical and planned methods based on geologic and hydrologic considerations and also political and economic implications. For this purpose the resource analysis of ground water is pre-requisite. The extent and capability of ground water basin, appropriate number of ground water structures, and the conjective use of surface and ground water are important items of study to organize the utilization of water for various purposes. Overdraft is an undesirable situation for the basin. Hence the inflow and outflow should always be in equilibrium maintaining the state of balance. The following methods are to be followed in the management of ground water.

DEFINITION OF GROUND WATER BASIN:

CONCEPT OF BASIN MANAGEMENT:

The groundwater basin may be defined as Hydrogeologic unit containing one large aquifer or several connected or interrelated aquifers. Such a basin may or may not coincide with physiographic unit.

Ground water is a renewable natural resource; when a ground water structure is constructed, it functions constantly when the inflow and outflow to the basin remain in equilibrium. If the structures are more or if recharge is less, it affects the water levels thereby causing the decline in the functioning rate of structures. Hence the mis-management may lead to the depletion of the water table in the basin. In terms of the hydrologic cycle for a particular ground water basin, a balance must exist between the quantity of water supplied to the basin and that leaving it. This hydrologic equilibrium provides a quantitative measure of this balance.

ie., INFLOW = OUTFLOW

Surface in flow + Subsurface inflow +Precipitation+Imported water + decrease in surface storage + decrease in ground water storage

=

Surface outflow +subsurface outflow + consumptive use + Exported water + increase in surface storage + increase in ground water storage.

BASIN INVESTIGATIONS - DATA COLLECTIONS :

Topographic data :

Involves contour maps, Photographs, benchmarks, etc., They are related to locate the wells and their identification.

Geologic data:

Surface and subsurface geologic mapping provides the frame work for the occurrence and movement of ground water and hence is essential for feasibility studies. Subsurface information may be sought from geophysical surveys and drilling programme. Pumping tests are essential for the assessment of storage capacity and transmissibility of aquifers.

Hydrologic data:

The principal purpose of hydrologic data is to evaluate the hydrologic equilibrium. The data involves surface inflow and outflow, precipitation and consumptive use, changes in surface storage and soil moisture changes in ground water storage, sub-surface inflow and outflow.

ALTERNATIVE BASIN YIELDS

Mining yield :

If the drawal of ground water exceeds the recharge, the situation leads to mining yields in the basin. As a consequence the depletion of water table starts. The continuation of mining yields cause undesirable effects of total depletion of water table and lesser yields.

Perennial yields:

Perennial yields are limited to the specified rates of pumping out water within the limits of recharge. This involves the non-drawal of water to the stage of over draft and the quality deterioration.

Salt balance:

Quality deterioration is also observed while using ground water in basin on large scale. This may be due to stagnation and also dissolution of the aquifer materials and added to ground water body. Proper drainage facility and pumping out water at appropriate rate may maintain the salt balance in the basin.

BASIN MANAGEMENT BY CONJUCTIVE USE :

The conjuctive use involves co-ordinated and planned usage of both surface and ground water. The concept of conjuctive use is predicted on surface reservoirs impounding stream-flow which is transferred at an optimum rate to ground water storage.

Management by conjuctive use requires physical facility for water distribution for artificial recharge and pumping. The method involves the requirement of the data on surface water reservoirs, ground water reserves and geologic data.

CONCLUSIONS:

The utilitarian aspect of ground water in a basin should be done in a systematic way by following the scientific method by selecting appropriate number of ground water structures as per the reserves. If mismanagement is done, undesirable effects set in leading to the total depletion of water table and lesser yields of the structures.

Eg: Yerragondapalem mandal in Prakasam District may be cited which has been declared as a gray area because of the larger number of ground water structures.

❑

Chapter 11

GROUNDWATER PROVINCES OF INDIA

Introduction
Peninsular Provinces
Ganges - Brahmaputra Alluvial Province
Himalyan High Land Province

INTRODUCTION:

Ground water province is an area characterized by a general similarity in the mode of occurrence of groundwater. According to Mienzer, the following criteria are used for the determination of ground water province.

i. A large area in which one group of aquifers exists
ii. Where more than one of the principal groups of aquifers occur, the extension of the most important of these determines the limit of a province.
iii. In rugged and lofty mountainous regions the topography and to some extent the climate produce radical changes in ground water conditions which eclipse the difference due to the presence of different groups of aquifers.

Physiographically and geologically India falls into three principal divisions, namely the Peninsula, Ganges-Brahmaputhra alluvium (Indo-gangetic alluvium) and the Northern mountain Zone. The divisions are very suitable for separating the main water province. Topography determines the manner of occurrence of water in northern mountain zone, through varied geological formations occurring in this zone. The Ganges-Brahmaputra alluvium forms a single geological unit composed of recent fluviatile sediments, many of them with high porosities and Transmission coefficients. With respect to the occurrence of ground water, India can be divided into eight provinces lying in three major regions. Taylor proposed this division in 1959.

a) Peninsular region:
It contains six ground water provinces

- i) Precambrian crystalline province
- ii) Precambrian sedimentary province
- iii) Gondwana sedimentary province
- iv) Deccantrap province
- v) Cenozoic sedimentary province
- vi) Cenozoic Fault Basin

b) Ganges - Brahmaputra Alluvial Province

c) Himalayan High Land Province

PENINSULAR PROVINCES:

In India, large number of ground water structures in various litho-units of hard rocks display wide variations in the yield characteristics. Weathered zones and fractured zones are the principal water-bearing horizons that yield ground water.

Hydrological information brings out clearly that the fractured zones have higher yield potential in comparison to the weathered zones. Also among the various lithounits, the traps seem to possess fractures down to greater depths and have the potentiality to produce significantly larger yields under favourable conditions.

PRECAMBRIAN CRYSTALLINE PROVINCE:

This province covers a major portion of the peninsular India, extending from Kanyakumari to Delhi. Plutonic Igneous and metamorphic rocks of Precambrian basement (Archean) consisting chiefly of Granites, Gneisses, Schists, Quartzites, Phyllites, Marbles, etc. are the major rock formations of this province. Ground water occurs mainly in weathered and fractured zones of these rocks within depths of less than 50 m. Occasionally, Ground water occurs at a depth of 100 m.

Ground water development is largely through large diameter dug-wells and bore-wells. They have a discharge ranging from 20 to 200 m^3/d. Generally ground water contains less than 1000 ppm of dissolved solids. But in some localities the water is brackish (or) saline. In the Westernghat region because of good drainage the dissolved solids are less than 200 ppm. Hardness is also low in these areas. High concentrations of Fluoride have been reported in many areas of this province such as A.P (Nalgonda and Prakasam dists.), TamilNadu and Karnataka.

PRECAMBRIAN SEDIMENTARY PROVINCE:

This province includes the following four discrete structural basins i) Cuddapah basin including kurnool group ii) Raipur basin iii) Vindhyan basin iv) Western Rajasthan basin.

The important rock types of this province are Shales, Slates, Sandstones, Quartzites, Limestones, Conglomerates, etc. This province covers the parts of the states of A.P, M.P.,Karnataka, Orissa, Rajasthan and Haryana.

Due to compaction and cementation the primary porosity is less in these formations. Ground water circulation is mostly through bedding planes, cracks, joints, and other secondary fractures. At some places limestone exhibits cavernous and solution openings thereby forming potential zones of Ground water.

Recovery of Ground water in this province is obtained from dug-wells, dug-cum-borewells and bore-wells. Bore-wells tap the fractured zones, solution channels and bedding planes. The yields of dugwells vary from 10 to 100 m^3/d. The chemical quality of ground water in this province is inferior when compared with the water from the precambrian crystalline province. The dissolved solids exceed 1000 ppm.

The water from sandstone of this province is good to better in quality when compared to the water from limestones, shales and other formations. However, the water is generally suitable both for drinking and irrigation.

GONDWANA SEDIMENTARY PROVINCE :

This province comprises more than a dozen faulted troughs, structural basins, containing mainly fluviatile or lacustrine of consolidated or semiconsolidated sedimentary formations. Here the main rock formations are Sandstones, Shales, Clay beds, Grits and Basal Tillites. The rocks of this province belong to Gondwana sequence ranging in age from upper carboniferouis to lower cretaceous. They are mainly developed along Mahanadi, Narmada, Sone, Damodar, and Godavari valleys, and Western parts of Rajasthan, Kutch and Saurashtra areas, and in scattered patches along the East Coast. The total thickness of the sediments is about 6000 to 7000 m.

The water table lies generally at a depth of 30 m. Gondwana sandstones form as good aquifers and at places they have given rise to flowing wells (Khammam dt in A.P. , Surender nagar dt in Gujarat). Dug-wells in productive sandstones yield nearly 400 m^3/day. Groundwater in this province usally contains less than 1000 ppm of dissolved solids. In Western Rajasthan and Kutch basins the quality deteriorates locally. Water associated with coal seems is sulphurated.

DECCAN TRAP PROVINCE:

This province occupies an area of about 5,00,000 Km^2 covering parts of Maharastra, Karnataka, A.P., M.P., and Gujarat. This province comprises a series of Basaltic fissure flows. The traps are weathered, jointed and fractured. Intertrappean beds occur between certain flows. The occurrence and movement of ground water in this province is controlled by

i. Nature of the Trap (vesicular, Amygdaloidal, Zeolitic massive)
ii. Degree of weathering
iii. Intensity of fracturing and jointing (columnar joints)
iv. Nature of junctional planes between Deccan traps and Inter Trappeans.

Groundwater occurs in the shallow weathered zone, vesicular and zeolitic zones and well jointed fracture zones. In this province, groundwater is developed by dug-wells and dug-cum-borewells. Ground water occurs under both unconfined and confined conditions in the trap rocks. The yields of borewells drilled down to a depth of 40 to 120 m ranges between 10 to 180 m^3/h. The chemical quality of ground water of this province is generally good and the total dissolved solids are usally less than 1000 ppm. But in areas underlain by thick Black cotton soils, the water is brackish to saline.

CENOZOIC SEDIMENTARY PROVINCE:

This province comprises

i. Three coastal plains and the Malabar and Coramandal coasts
ii. Coastal fringes of the Saurashtra and Kutch peninsula.
iii. An extensive embayment (sea covered area) in western India.
iv. A belt of strongly folded rocks in Eastern India.

This province consists of shales, sandstones and conglomerates as the main rock types. Conglomerates and Sandstones where well sorted, purely cemented are highly permeable and form good aquifers. Water is confined under artesian pressure in the coastal regions. Recovery of ground water in this province is mainly obtained from percolation wells, dugwells, artesian wells and tube wells. In Krishna-Godavari area in A.P., Cauveri-Paleru area in Tamilnadu artesian aquifers occur. The discharge is more than 100 m^3/h. Tube wells commonly yield 50 to 200 m^3/h in the Coramandal coast.

The quality of ground water deteriorates towards the coast. But in the uplands the groundwater usually contains less than 1000 ppm of dissolved solids. In coastal plains of Saurashtra and Kutch, the groundwater is of inferior quality. The dissolved solids range 2000 to 5000 ppm. Due to depthwise increase in salinity, the wells are commonly dug or dug-cum-borewells.

CENOZOIC FAULT BASIN:

This province comprises three distinct fault basins. i) The Narmada ii) The Purana and iii) The Tapati valley.

Each basin consists of an extensive fill of unconsolidated Quarternary alluvium, mainly sand and gravel intercalated with silt and clay. Sand and gravel lenses form as good aquifers in this province. Recovery of groundwater is mainly obtained from tube and dug wells. Groundwater in Naramada and Tapati valleys contains 100 to 500 ppm of dissolved solids. But in parts of Purna valley the ground water is highly saline. The yield is in between 25-150 m^3/h.

GANGES- BRAHMAPUTRA ALLUVIAL PROVINCE:

This province covers an area of 8,50,000 km^2 covering vast planes of Ganges and Brahmaputra. These planes are underlained by upper Tertiary and Quaternary alluvium which has been deposited in a fore deep. The vast and thick alluvial fill constitutes the most potential and productive groundwater reservoir.

Ground water occurs in these distinct physiographic and hydrologic belts. 1) Bhabhar 2) Terai 3) Axial.

The groundwater is mainly obtained from tube and dug wells and springs. The general range of groundwater yield is 100 to 300 m^3/h and the water contains less than 500 ppm of dissoved solids.

HIMALAYAN HIGH LAND PROVINCE:

This province includes highly folded and faulted sedimentary rocks from Kashmir to Arunachal Pradesh. In this province the main rock types are limestones, sandstones, shales and their metamorphic equivalents, which are highly deformed by thrust faulting and folding in orogeny of Himalayas. Valleys are partly filled with Quarternary alluvium. The groundwater is obtained through springs and dug-wells. The dissolved solids in water are less than 500 ppm.

❏

Chapter 12

GROUND WATER PROVINCES OF A.P.

Introduction
Precambrian Crystalline Province.
Precambrian Sedimentary Province.
Gondwana Sedimentary Province.
Deccan Trap Province.
Cenozoic Province including coastal plains.

INTRODUCTION:

A.P. is geographically located in peninsular India(S_E part) covering about 2,76,254 sq.km. It has a coast line of about 972 km in length. Geologically A.P. comprises Archeans,Cuddapah, Kurnool, Gondwana, Deccan Traps & Cenozoic, Quaternary sediments. Basing on the water-bearing & water-yielding properties of rocks, the Groundwater provinces can be broadly grouped into the following:

i. Precambrian crystalline province. ii. Precambrian sedimentary province. iii. Gondwana sedimentary province. iv. Deccan Trap Province. v. Cenozoic province including coastal plains.

PRECAMBRIAN CRYSTALLINE PROVINCE:

This province covers hard and consolidated rocks such as Granites, Gneisses, Schists, Khandolites, Charnokites, Alkaline rocks, Dolerites, Pegmatites etc., From the groundwater potentiality point of view, all these rocks are considered as crystallines. They are hard and compact and impervious. Primary porosity is ususlly absent in them. But weathered zones, fractured zones, joints & shear zones are the principal water-bearing horizons that yield ground water. Hard rocks, particularly when the depth of weathering is high, form as favourable zone for the groundwater accumulation. The intensity of jointing & weathering usually decreases with the depth.

So these rocks do not contain appreciable quantities of water below the depth of 60 m. The depth of water table is highly variable in these rocks depending on the topography and geohydrological setup. Generally groundwater is developed from these rocks by means of large diameter open-wells, dug-wells, borewells. Open-wells have a discharge ranging from 20-200 m^3/days Bore-wells have an yield of 25 m^3/hr.

Groundwater in these rocks contains less than 1000 ppm of T.D.S.But in some localities, particularly in coastal areas, the water is brackish or saline. This may be due to sea-water intrusion. High concentrations of fluoride have been reported in many places of this area such as Darsi, Podili, Kanigiri of Prakasam dist. and in parts of Nalogonda dist.

PRECAMBRIAN SEDIMENTARY PROVINCE:

This province includes the following geological formations:-

i. Cuddapah super group
ii. Kurnool group
iii. Pakhal group
iv. Sullavai group in Godavari valley

The important rock types of this province are Sandstones, Shales, Quartzites, Limestone, Conglomerates, Siltstones, Phillites, etc. Due to cementation & compactions, the primary porosity is less in these rocks. Groundwater circulation through bedding plane, joints, solution openings in limestones and other secondary fractures, cavernous limestones and highly jointed quartzites & Sandstones form as good aquifers in this province. Shale & Calcareous slates are impervious and they form as poor aquifers.

However, Tadipatri shales with moderate to high dips and fracture zones & Joints form favourable conditions for groundwater storage. Sullavai sandstone in warmth is formed as good water zone with good yields ranging from 30,000- 90,000 ltr./hr. Limestones of Cuddapah, Guntur, Kurnool, Adilabad, and Jaggayahpet areas are highly productive for the constructions of bore wells. Recovery of groundwater in this province is obtained from an increasing number of bore-wells, dug-wells and dug-cum- borewells. Yields of borewells range from 2,500 to 22,000 lit/hour.

The chemical quality of ground water in this province is inferior when compared with the water from precambrian crystalline province. The T.D.S exceeds 1000 ppm. The water from sandstones of this province is of better quality than that derived from limstone formations. However, the water is generally suitable both for drinking & for Irrigation.

GONDWANA SEDIMENTARY PROVINCE:

Gondwana groups of rocks occupy an elongated strip of land trending NNW-SSE in parts of Adilabad, Karimnagar, Warangal & Khammam districts of A.P in Godavari basin. Scattered exposures of upper Gondwana are found in coastal districts of A.P., ie. East & West Godavari, Guntur and Prakasam districts and Satyavedu area in Chittoor dist., Gondwanas include thick sections of Sandstone, Shales, Clay beds & Grits. From the groundwater point of view, productive aquifer horizons are Kamthi, Barakar , Chintalapudi, Gollapalli and Budawada sandstones. Ground water development in these formations is mostly from dug-wells, bore-wells and dug-cum-bore wells. Transmissibility range of some gondwana aquifers is given below:-

Barakar sandstone	*18-84 m²/day*
Talchir sandstone	*20-30 m²/day*
Kamthi sandstone	*28-950 m²/day*
Chintalapudi sandstone	*56- 303 m²/day*
Gollopalli sandstone	*80- 900 m²/day*
Tirupathi sandstone	*86-1900 m²/day*

All these Gondwana sandstones are highly porous and permeable constituting promising aquifers. The quality of groundwater from gondwana formations is good. Groundwater in this province contains lessthan 1000 ppm of total dissolved solids. But in coastal traps of Guntur and Prakasam dists. groundwater became Saline due to sea-water intrusion.

DECCAN TRAP PROVINCE:

Deccan traps in A.P are restricted mainly to parts of Medak, Mahaboobnagar and Adilabad dts in Telangana region. Small patches of Deccan traps are exposed near Rajahmundry and other areas in East Godavari dist. These traps are underlain by Infra-trappeans (Sedimentary). Where Deccan traps are thin, the underlying sedimentaries form as potential aquifer. Ground water occurs in weathered Zones, vesicular opening, and joints fracture zones of Deccan Traps.

In the trap province, groundwater is developed by dug-wells and dug-cum-borewells. The general yield of borewells drilled down to a depth of 40 to 100 m, ranges from 1000 to 4000 lit/hour.

The chemical quality of groundwater in this province is generally good since the totally dissolved solids are less than 1000 ppm . But in areas underlain by thick black cotton soil, the water is brackish to saline because of the less drained nature of these soils.

CENOZOIC SEDIMENTARY PROVINCE:

This province in A.P covers Rajahmundry Sandstone, River Alluvium, valley fills, Coastal plains comprising quarternary sediments. Rajahmundry Sandstones belonging to Mio-pliocene age occur along the East coast from Eluru to Visakapatnam, covering parts of East & West Godavari dists. They occur as isolated outcrops. They dip gently towards the coast and they are mostly undisturbed. These sandstones, are highly porous and permeable. Artesian conditons prevailed at some places. It is one of the important geological formations from the groundwater point of view. The discharge rate of groundwater is more than 100 m^3/hour. Tube-wells yield 50-200 m^3/hour., in the coastal districts. The depth to water table varies from 0.5 to 15 mts. Ground water development is mostly by dug-wells, bore-wells & tube-wells. The yield of groundwater in coastal plains ranges from 20,000 to 65,000 litres/hour.

Alluvium :-

Alluvium occupies an area of about 20,000 km^2 along the coastal track. The thickness & width of alluvium increases in Krishna, Godavari deltas. The alluvium comprises clay, silt, sand and gravel. Ground water potentiality in alluvium is highly variable depending upon the thickness of the granular zones and their texure (sorting). Alluvium can be classified broadly into valley fills & coastal alluvium, Valley fills occur along the river courses such as Pennar, Chitravathi, Cheyyair, Papagni, Swarnamukhi, along the Krishna river and its tributaries, and also Godavari river and its tributaries.

The thickness of the valley fills ranges from a few mts. to about 50 mts. Valley fills consist of pebbles, gravel and coarse sand. Most of the valley fills have very high permeability . Hence they can sustain high capacity shallow tube wells. There is a good potential for the ground water development. Coastal alluvium consists of fine grained sediments of sand and clay. It covers along the coastal tracks with variable width. It is widest in the delta regions of Krishna & Godavari rivers. It is very narrow beyond Tandava river in Vizag District. It attains a width of 10-20 km in the south of Ongole. In coastal alluvium, dug-wells and filter points are common. But the quality of ground water is highly variable in coastal alluvium. It is saline at many places due to tidal effects of the sea in Krishna & Godavari dists. Ground water is saline even at depths close to the coast due to entrapped sea-water during sedimentation.

❏

Chapter 13

GROUNDWATER POTENTIALITIES OF PRAKASAM DISTRICT

Introduction
Hydrogeological Conditions in Crystallines
Hydrogeological Conditions in Cuddapahs
Hydrogeological Conditions in Gondwanas
Hydrogeological Conditions in Laterites and Alluvium

INTRODUCTION:

Hydrogeologically the Prakasam district may be studied under four heads, namely (1) Hydrogeological conditions in crystallines (2) Hydrogeological conditions in Cuddapahs (3) Hydrogeological conditions in Gondwanas and (4) Hydrogeological conditions in lataritic and alluvial deposits. The details are given under each head as follows:-

HYDROGEOLOGICAL CONDITIONS IN CRYSTALLINES:

The crystalline formation occupies the major part of the district in the Mandals such as Konakanamitla, Podili, Kanigiri, part of Donakonda, Pamuru, Ch.S.Puram, P.C.pally, Hanumanthunipadu, Kandukur, Ongole, Addanki, Ballikurava, Korisapadu and Santa Magulur Cheemakurthi,Santhanuthalapadu etc., The Ground water occurs under water table conditions in the weathered zone of this rock formation at shallow depth in cases of occurrence of wider jointing and fracturing. Bore-wells are also feasible at deeper levels in localized patches. In general the development of Ground water is done mainly by dug and dug-cum-bore wells in this formation.

The total depths of the dug-well zones range from 8-12 m and depth to water level varies from 4-6 m. The discharge ranges from 10,000 - 20,000 gph. with extremely exceptional cases of higher and lower discharges. In localized patches the bore-wells are also feasible at a depth range of 50 to 60 m with discharge range of 1,000-3,000 gph. In this formation, at Chinna Kothapalli, Kalavakur, Ranigavaram, and Yerrajerla, borewells were constructed at a depth range of 40-45 m and the yield ranges in between 1,000-2,000 gph.

The quality of Ground water in general is good in weathered and semi-weathered rock formation, but altered product of the crystal lines which are chemically weathered beyond limit of the optimum weathering. There is quality deterioration of groundwater because of the water-logged conditions in this clay patches, which may be considered as the authigenic sediment derived from the crystallines. In these clay patches there is not only deterioration of the Ground water quality but also meagre yields resulted because of the closure of the pore spaces by clay minerals derived from the highly altered rock formation. Such cases are observed in the Mandals such as Tangutur, Ongole, Santhanuthalapadu, Korisapadu, J.Pangulur etc.,

HYDROGEOLOGICAL CONDITIONS IN CUDDAPAHS:

Cuddapah formation in this district is the main source of Ground water development by means of Bore-wells. The peripheral zone of Cuddapahs occupied the entire Markapur division and western part of the district stretching in N-S directions. The Cuddapahs thrust against the crystallines in the east which form the impounding body for the basin. The Ground water occurs under water table in semi-confined conditions in the weathered and the inter connected pore spaces of shales, slates, phyllites etc., The quartzitic intercalations in this formation facilitate much more weathering and create the opening space. The vertical dips in this formation, dips of cleavage planes, and fracturing facilitate the water to percolate downward to considerable depths, rendering the formation feasible for bore wells and in low-lying areas dug and dug-cum-bore wells are also feasible. But at present the dug-well zone is not so encouraging because of the depleted conditions of water table effected by the increased number of irrigation bore-wells. Hence, this is favourable only for bore-wells and dug-cum-borewells to limited extent at sufficient spacing of 300-500 m. The general lithology of the bore-wells may be summarized as follows:-

0.00	*to*	*0.50*	*Top soil*
0.50	*to*	*6.00*	*Weathered shales*
6.0	*to*	*23.0*	*Fractured shales*
23.0	*to*	*42.0*	*Fractured shales with quartz veins.*
42.0	*to*	*50.0*	*Massive shales*

The quality of ground water is quite permissible for irrigation.

GROUND WATER CONDITIONS IN GONDWANAS:

The upper gondwana were depose and in warpings of the truncated border of the crystallines near Gudluru and Tettu of Gudluru mandal, Kandukur, Ponnalur and Pavuluru, Budawada and Vemavarm of Inkollu mandal. The exposures of sand stone with limited lateral extents and thickness occur near Budawada and Pavuluru which correspond to Gollapally to Tripathi sand stone of Rajahmundary area and shales at Vemavaram which correspond to Raghavapuram shales. The Vemavaram shales occupied the villages such as Vemavaram, Rachapudi, Uppugunduru etc., Adjacent to these exposures Gondwana gravel near Inkollu and Gangavaram are deposited. The Ground water in this formation is bracish and is not much suitable for irrigation as the yields are also meagre because of the streaks of clay. Shallow open wells are feasible in Pavuluru, Budawada, Ponnalur, Gudluru and Kandukur areas at a depth range of 9-10 m. Inwell bores are not feasible in these areas because of the occurrence of clay beneath the sandstone. Hence, Inwell bores are discouraging in the existing wells of these areas. In other areas near Tettu and Yendluru, there is only Gondwana clay which is not fit for Ground water Development.

GROUND WATER CONDITIONS IN LATERITES AND ALLUVIUM.

There is no considerable thickness of productive lateritic patch, yielding workable Ground water in the district. The limited extent of lateritic patches occur near S.Konda, Tangutur, and Gudluru areas. The water in this patch is highly saline and the yields are also meagre rendering Ground water unfit for its development except in few localized areas such as Revuru etc.,

Limited lateral extents of alluvium are deposited in river courses of Gundlakamma, Musi, Paleru and Manneru. The alluvial tracts in Gundlakamma basin occur in the mandals such as Addanki, Maddipadu and Ongole. In the upstream side of this river course beyond these mandal areas there is no deposition of alluvium. Because of the less lateral extents, the quality of Ground water is bracish in the mandal areas of Ongole and Maddipadu except in localized patches. In the villages such as Dhenuvukonda, part of the area is covered by alluvial deposits of this river and filter points are functioning to develop Ground water economically at a depth range of 10-12 m. Such comparable patches are less in the alluvial tracts of this river. In Maddipadu area filter points are functioning at a depth range of 15-20 m and 50% of the area is yielding brackish water. In Ongole mandal the Ground water in this alluvium is highly saline at Ulichi, Devarampadu, Kanaparthi etc., rendering unfit for Ground water development. In the case of proximity of surface water bodies, there are certain patches yielding fresh water developed by ring wells and shallow filter points useful for domestic purposes. Abutting this Gundlakamma river alluvium major part of the area is occupied by clay patches without any productive sand zone thus rendering it unfit for Ground water development.

The alluvial deposits of Musi river occupy the parts of some villages in Tanguturu and Kothapatnam (Mandal) villages such as Ponduru, Madanuru, M. Nidamanur etc., In Ponduru Jayavaram and Nidamanur the filter points are feasible at a depth range of 10-15 m. In the case of Madanuru the alluvium is mixed type of both river and coastal, and filter points are feasible at a depth range of 10-30 m. In major part of the river course there is no favourable zones of alluvium with productive sand zone. As such is the case adjacent part of the river course is more chemically altered and forms as authigenic sediments yielding highly brackish water with meagre yields.

Paleru is the 3rd river course at closer intervals between Manneru on southern side and Musi on Northern side at a distance of 5 to 6 kms apart. The alluvial deposits occur on either side at a distance of 5 to 6 kms apart. The alluvial deposits occur on either side of Paleru and parts of Zarugumalli and S.Konda mandal areas. The villages, namely Kamepalli, Kommavaripalm, Narasingolu, Chatukupadu, Zarugumalli, Vaviletipadu are partially occupied by the alluvial deposits of this river on northern side. The villages such as Vikkiralapet, Nandanavanam,K.Bitragunta etc., are partially occupied by alluvial deposits of this river on southern side. In both the cases filter points are feasible at a shallow depths of 10-15 m. In localized patches the Ground water is brackish at Zarugumalli, Vaviletipadu etc.,

The filter point constructed at Nandanavanam has yielded brackish water with the conductance 5,000 microseimence cm. In these filter point range of quality deterioration is from 1250 microseimence/cm to 5000. The discharge of filter points ranges from 3,000 to 5000 gph.

Manneru is the southern-most river course of Prakasam District. It forms alluvial deposits in the villages of Mannetikota, Puritipalli, Darakanipadu, Machavaram, Karedu on southern side and Sanampudi etc., North side of Gudluru and Singarayakonda mandal on northern side the alluvium is very limited. Filter points are feasible in the major part of the alluvial tracts on southern side of the river right from Madavaram to Karedu at a depth range of 10-15 m with a discharge of about 3000 gph.

The coastal alluvium forms productive fresh water pockets all along the coastal line towards the east of Buckingham canal, i.e. in mandal areas such as Chirala, Vetapalem, Chinnaganjam, Naguluppalapadu, Kothapatnam, Ulavapadu, Tangutur, S.Konda etc. Of these the productive zone yielding fresh water with a discharge of 2000 to 3000 gph at a depth range of 8 to 15 m, occurs between Motumala and Madanur. Except at Karedu where there is confluencing effect of Manneru river the filter points are not feasible. The other areas of coastal line because of the occurrence of loose sand yield fresh water at shallow depths. In this zone ring wells are feasible in the mandal areas of Chirala, Vetapalem, Chinnaganjam etc., In localized patches filter points are also feasible in the villages such as Chinnaganjam at a depth range of 8 to 10 m.

The productive zone between Motumala and Madanur of Kothapatnam mandal and also near Karedu of Ulavapadu mandal may be attributed to the confluence effect of river courses of Gundlakamma and Musi in the former case and Manneru in the latter. These rivers might have deposited productive alluvium and thus forming the mixed type of coastal and river alluvia. Because of this feature filter points of fresh water are feasible along the coastal line in between the confluence points of these rivers. Nowadays more filter points are constructed in these areas and sprinkler irrigation has been adopted because of the sandy soil.

In recent years Aqua-culture has gained much importance along the coastal line. The length of the coastal line in Prakasam district is 103 kms, starting in Chirala mandal and ending in Gudlur Mandal. This is 10.3% of the total length of coastal line of the state. The aqua culture has been taken up along this line between sea-shore and the Buckingham canal and also on either side of rgw canal. If sufficient precautionary measures are not taken, there is every possibility for the pollution of the ground water and thereby it may have the way for sea-water encroachment further inland. Hence precautionary measures such as providing clay membrane and grouting of the bunds of peripheral tanks are to be taken to avoid seepage effects. Sufficient margin around the aqua farms may be left out so as to avoid logging effects in the adjacent lands of others which evacuate the waste water which causes utmost pollution. Technical method must be adopted for the proper treatment before letting out into the drains or sea.

❑

Chapter 14

ON FIELD

Groundwater Problems as Assessed from Field Experiences

i. Semi-Weathered formation yields less: Pore spaces or interstices (openings) are not well developed for accumulation and movement of ground water. This is the case of upland areas of higher gradients. Foot hill zones, ridges of higher relief etc.,

ii. Intensive weathering to the stage of chemically altered products of mineral assemblage of rocks also yield less with poor quality of ground water. In this case the openings and the fractures are sealed up with the chemically altered minerals such as clay etc., Hence the stagnation of water results without any free movements leading to less yields with brackish water Eg: Low-lying areas.

iii. Low- Lying areas represented by black soils lead to water-logged conditions whereas the upper zones in the same rock terrain contain red soil with fresh water even though the yields are less.

iv. In lowlying areas, the humus in the black soil plays an important role in causing deterioration of ground water quality in addition to the intensive weathering of lithological units. At higher relief there is no stagnation of ground water because of gradient and the quality of water that percolates maintaining its freshness as there is no influence of the altered products. Eg: Kondaveedu hill ranges in Guntur District. The Chodavaram area is extended up to Kondaveedu hill range on the west of National Highway yielding fresh water whereas the eastern part is occupied by black soils yielding brackish water around the village site and also further east. Innumerable examples may be cited.

v. In an undulatory terrain the geophysical depth indications are less even at the favourable sites because of the encountrance of hard masses along the alignment in the vicinity. Eg:- Vinjamuru area in the Nellore Dist., Areas in between Nallpadu and Perecherla in Guntur dist. and Kotappakonda in Prakasam Dist.

vi. Mineralisation in hard rock terrain may lead to the yields of brackish water inspite of favourable geophysical indications. This is because the bulk resistivity of the terrain is higher and favourable but the ground water is confined to the jointed and fractured zone where mineralization has taken place, contaminated ground water exists. Such mineralisation may be sericitisation as the mineral sericite is formed only in saturated solution of sodium chloride. This case has been studied during surveys and drilling in Kanupur canal of Nellore district near Bujibuji Nellore. The geophysical indication is 60-120 ohm-meters whereas the conductance of ground water as recorded during drilling is 5000 microsiemence/cm which is unsuitable for normal crops in the area.

vii. Furrowed or grooved nature of hillocks with constrictions are more favourable for the localization of ground water in the vicinity around them rather than massive hillocks. Eg: Furrowed hillocks:- Kondaveedu hill range between Edlapadu and Guntur, hillocks between Nidumukkala and Endryi on the way to Amaravathi. Massive Hillocks:- Vinukonda hills, Phiranagipuram hill. One can see the clear cut distinction in the feasibility and non-feasibility of Ground water structures around these hillocks respectively. In a furrowed nature of hillocks the drainage channels start from the hillocks and drain the area cutting across and does facilitate the favourable recharge. But in the case of massive hillocks the area around them is bun-shaped and the water that falls spreads all over the foot-hill zone and parallel drainage to stretch of hills is resulted at farther place.

viii. The pedalogical features are of paramount importance in the accumulation of ground water. Well sorted gravel or sand are more favourable rather than the clay and silts and other ill stored sediments. The Junctional plains of soils of different textures i.e., coarse, medium and fine grained, are more favourable sites for the feasibility of ground water structures. Eg. Anamanamur in Addanki (Mandal) of Prakasam District.

ix. Parallel sets of lineaments that control the valleys are more favourable for ground water accumulation. Lineaments that connect hillocks and ridges, dykes only function as impounding bodies or drainage structures and thus create potentialities in their vicinity. Eg:- Parallel sets of lineaments near Sanjivarao pet and Gadikota of Giddalur mandal of Prakasam dist. 2) Hillocks near Mothadaka, Nidumukkala, Karlapudi in Guntur dist.

x. Clay barriers function as impounding bodies for the accumulation of ground water in the vicinity. Eg. The clay formation around the potential tracts between Badepuram and Yendrai covering 4 to 5 villages in which bore-wells are feasible at Nidumukkala, Mothadaka, Karlapudi in Guntur District.

xi. The confluencing points of rivers forming mixed type of alluvium are productive for the feasibility of low yielding filter points along coastal lines. The perched aquifers may be formed to yield fresh water in coastal areas due to upliftment of fresh water pockets. Eg. Fresh water pockets between Motumala and Madanur. (Confluencing points between Gundlakamma and Musi river). 2) Around Karedu, influenced by Manneru river in Prakasam District.

xii. In alluvial tracts and also soft rock terrains such as sand stones the parametric soundings (Test soundings) give more valuable and reliable information for the proper assessment of potentialities in the terrain. Based on the considerable thickness especially in the case of sandstones feasibility may be given for the construction of tube-wells. Ex: Anamarlapudi and Sekuru in Guntur District.

xiii. The intersecting sites of nallah cuttings along slope directions are the favourable sites for the accumulation of ground water.

xiv. The two-way or three-way slope directions are more considerable in locating favourable sites for the accumulation of the ground water. Eg:- Surveys for bore-wells at Vinjamur in Nellore District.

xv. Mud conductivity has to be recorded from time to time during rotatory drilling in Alluvial tracts and also soft rock terrain for the proper assessment of ground water quality. Even the smaller rises in conductivity values are more considerable as there is every possibility of encounterance of brackish and saline water. The rises in the values are small because of more fresh water of certain conductivity is used in the circulating fluid. During drilling, the addition of ground water is less as the walls are sealed up with Bentonitic mud. Hence only the smaller rises are recordable during drilling whose effect is more considerable and indicating the poor quality of ground water. Ex. Rotary drilling at Nandanavaram of Singarayakonda mandal, Prakasam District in Paleru Basin.

xvi. Nature of cuttings during drilling suggests the structural pattern of the rock formation. Powder may be accounted for hard rocks. Flaky chips may be attributable for the fracture zone. Bigger angular or block cuttings may be considered for the jointed zone.

xvii. Collapsing due to raising sand during drilling may be arrested by increasing the rate of drilling with circulatory fluid of appropriate viscosity. Ex: Drilling at Nandanavanam with Rotary rig.

xviii. Quality deterioration is observed at the contact zones of hard and soft rocks in crystalline and alluvium, laterite and alluvium; and sand stone and alluvium. Ex: Laterite and alluvium in Guduru area of Nellore District. 2. Sandstone and alluvium in Narakodur area of Tenali Mandal in Gutnur Dist. 3.Sandstone and crystalline in Gudlur, Ponnaluru area in Prakasam Dist.

xix. In most of the cases clay is encountered beneath the sand stone, and piercing depth further is not advisable for the construction of groundwater structures. Eg. Pamidipadu in Prakasam District, Anamarlapudi in Guntur District.

xx. Talus material: Talus material is the loose weathered debris that trickles down the hillocks and deposits at the foot hill zone. If sufficient thickness of Talus accumulates, such deposit is potential for dug-wells.Eg. Yarada Park, Near Light house, Vizag.

xxi. Drainage divides are devoid of Ground Water because of Sub-surface drainage. Terrain adjacent of Alluvial tracts or river basins may be cited as example. Chakrayapeta area of Lakkireddipalli Taluq of Cuddapah district area besides Papagni river. Eg. Krishna-Pennar river alluvial in Guntur & Nellore Dist. Such sites lead to failure; even the Geophysical soundings are favourable.

xxii. Cavernous Lime stones are more productive for Ground Water development. Sink holes and ribbed weathering are the features of Karst Topography. Eg: Near Borra Caves Subterrain channels lead to Gosthani River. Massive Limestones are not favorable for Ground Water development. Eg: Piduguralla area in Guntur district.

❑

Chapter 15

WHAT'S WHAT

Aquiclude : Aqua means water, clude means shut or close. A geologic formation although porous and containing water, not capable of transmitting water because of high resistance to flow. Ex: Clay lenses, shales, etc.

Aquifer: Fer means to bear. A geologic formation containing water in its voids and which yields significant quantities of water. Ex: sandstone, gravel etc.

Aquifer Confined: It is completely saturated aquifer whose upper and lower boundaries are impervious layers. In nature completely impervious layers rarely exist. In confined aquifers, the pressure of the water is usually higher than that of the atmosphere. The water in a confined aquifer is known as Artesian Confined water.

Leaky or Semi-confined aquifer: This is a completely saturated aquifer that is bounded above by a semi-pervious layer, and below by a layer that is either impervious or semi-pervious. A semipervious layer is defined as a layer which has a low, though measurable, permeability.

Unconfined aquifer: This is a permeable bed only partly filled with water and overlying a relatively impervious layer. The water in an unconfined aquifer is called phreatic water.

Aquitard: A geologic formation of a semipervious nature, which transmits water at a slow rate, when compared to an aquifer. Ex:- clay lenses interbedded with silt or sand.

Aquifuge: Fuge means to drive away. A geologic formation containg no interconnected pores and which therefore can neither absorb nor transmit water. Ex:- Basalt, Granite etc.

Artesian Structure: A series of sedimentary rocks disposed in a way that an aquifer holds water under a pressure head between two layers of impermeable strata.

Artificial Recharge: It is the practice of increasing the amount of water that enter a groundwater reservoir by artificial means and this is accomplished by augmenting the natural infiltration of precipitation or surface water into underground formation by some method of construction, spreading of water or by artificially changing the natural conditions. Artificial recharge is one method of modifying the hydrological cycle and thereby providing groundwater in excess of that available by natural processes.

Darcy's law: Henry Darcy, the French Scientist found that the discharge of groundwater is directly proportional to the hydraulic slope and cross sectional area of an aquifer that is transmitting the water. It is expressed as $Q=VA$ and $V=KI$. Therefore $Q=KIA$ Where Q=discharge, K=hydraulic conductivity, I=change in elevation divided by the distance travelled, A=cross sectional area of the aquifer and V=velocity of flow.

Depletion: Continued withdrawal of water from a surface or stream of Ground water or reservoir or basin at a rate greater than the rate of replenishment.

Discharge of a stream: The total volume of water passing a given point in a given time.

Draw down: In a well means the extent of lowering of the water level when pumping is in progress or when the water is discharging from a flowing well. Draw down=static water level - pumping level.

Drainage basin: The total area that contributes water to main stream via its tributaries; and sheet wash is the drainage basin of the major stream.

Drainage divide: A divide is a height of land separating drainage basins.

Electrical conductivity: The reciprocal of electrical resistivity. The resistivity is the resistance in ohms of a conductor, metallic, which is 1cm long and has a cross sectional area of 1 cm^2. Hence electrical conductivity is expressed in reciprocal ‘ohms - cm'.

Evaporation: Emission of water vapour by a wet or a free surface of water, in liquid or solid state, at a temperature below critical point.

Ground water: Body of water which occurs in the saturated zone and where motion is determined by gravity and the frictional forces produced by the motion itself.

Ground water hydrology: The science of occurrence and distribution of water below the surface of the earth.

Hydrologic cycle: The route that earth's water takes, from precipitation onto the earth's surface, to its movements on or near the surface, and finally, to evaporation-transpiration back into the air.

Hard Water: This is the ground water that contains dissolved calcium carbonate and magnesium. It makes a scum when soap is added to the water.

Hydrology: May be defined as the science of water and does deal with occurrence, circulation and distribution of water of the earth and its atmosphere. As a branch of Earth science it is concerned with water in streams, lakes and rainfall water occurrences below the surface of the earth in the pores of soil and rocks.

Hydrogeology: Deals with the hydrological aspects in relation to the nature of lithological units of the earth. It mainly deals with ground water origin, occurrence and movement in different rock terrains and its development through different types of wells. Both Hydrology and Hydrogeology are interrelated subjects. Geohydrology differs from hydrogeology only by its less emphasis on Geology.

Hydrograph: This is a graph showing the time distribution of water level in a well or stage of a river.

Infiltration: This is the forcible penetration of precipitation into the ground surface of the earth through the openings.

Isohyet: This is the line connecting points of equal rainfall.

Lineament: It may be defined as the directional trend of linear structures on the surface of the earth, and they are recorded by remote sensing.

p^H *of pure rainfall:* It is about 5.6. This is acid too, but acid rain is defined as rain that is more acid than normal rainfall.

Perched water table: This is a local water table that is at higher elevation than the main water table and generally exists largely because of the presence of an impermeable layer such as shale beneath it.

Permeability (K): This is the ability of sediment or a rock to transmit water i.e., to allow water to pass, through connected pores. A material can be porous and yet be impermeable as eg. Pumice.

Porosity (N): This is the ratio of the total volume of voids (pores) to the total volume of rock or soil containing the pores. The range of porosity varies from 0.2 to 0.6. Porosity = volume of pores/total volume of mass. Porosity is thus a measure of water/holding capacity of lithological formation.

Precipitation: This denotes all sorts of the water that reaches the surface of the earth.

Runoff: This may be defined as the water that falls on the ground, flows from higher gradient to lowlying areas. Hence all sorts of water that flow in favourable channels in any other direction on the surface of the earth may be taken as run off.

Sea-water intrusion: The sea-water intrusion may be defined as an entry or encroachment of sea water into coastal aquifer, when the discharge of groundwater into the oceans is decreased due to known reasons. The contact surface in between the salt water and fresh water is known as Interface.

Specific Capacity: Specific Capacity of a well is its yield per unit of draw down usually expressed as gpm/ft of draw down.

Specific retention: The percentage of water retained in the rock is called specific retention.

Specific yield: The amount of water that drains from saturated rock under the influence of gravity, expressed as a percentage of the total volume of the rock is called specific yield. This is often called effective porosity, because it represents the pore space that surrenders water to wells and so is effective in supplying water for human use.

Springs: A spring is a natural discharge point where ground water issues from rock or soil in concentrated flow.

Static water level: This is the level at which water stands in a well when no water is being taken from the aquifer either by pumping or by free flow.

Watershed: Watershed may be defined as a Physiographic unit having definite boundaries within which the precipitated water will be drained towards the common channels and let out through single or limited outlets.

Water table: The upper surface of the zone of saturation under atmospheric pressure.

Zone of Aeration: This is the zone from ground surface to water table, comprises soil water, intermediate and Capillary zones. Water in the zone of aeration is called vadose water.

Zone of saturation: This is the zone below the water table. ❑

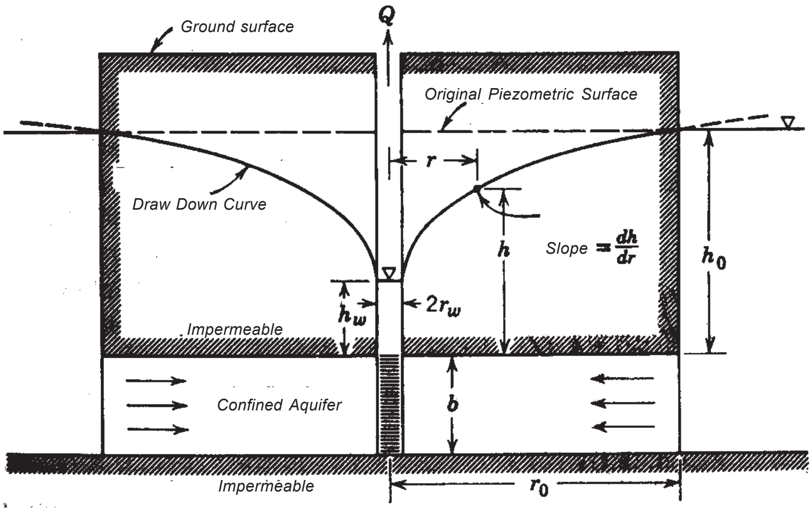
Appendix 1

CONE OF DEPRESSION - INTERFERENCE EFFECTS - SPACING

During pumpage the static water level around each pumping well declines taking depressed conical shape. This is called cone of depression and is depicted in figure.

The perfection of conical shape around the pumping structure depends on the boundary effects. In Isotropic medium (of uniform conditions) the perfection of cone depression in all sides is more pronounced rather than in an isotropic medium of Non-uniform conditions, in which the cone depression is more flattened, based on the proximity of the boundaries. During the development of cone of depression the depressed static water level in the pumping well affects the water level in the neighbouring wells in the vicinity and thus causes the interference effects.

Such interference of water level in the nearby wells leads to decline of the discharges and also failures in some cases. The intensity of interference effects depend on the rate of pumpage, type of usage etc., To avoid such interference, sufficient spacing should be maintained between two adjacent wells. The stipulated spacing does depend on the potentiality of the aquifer, type of usage and pumping rate in an area. Hence pumping tests should be conducted to suggest proper spacing for safe yield and proper utility of ground water. ❑



Cone of depression

Appendix 2

CONVERSION FACTORS AND CONSTANTS

Length

1 in = 2.540 cm

1 ft = 12 in. = 30.48 cm

1 yd = 3 ft

1 mile = 5280 ft = 1.609 km

Volume

1cm^3 = 0.264 x 10^{-3} U.S. gal

1 ft^3 = 7.48 U.S. gal

1 U.S. gal = 3.785 liters

= 231 in^3 = 0.134 ft^3

= 3.07 x 10^{-6} acre-ft

1 acre-ft = 43,560 ft^3

= 3.26 x 10^5 gal

1 cfs-day = 1.98 acre-ft

Specific Weight

Water:1 ft^3 = 62.37 lb at 60°F

= 62.31 lb at 20°C

1 gal = 8.338 lb at 60°F

Area

1 sq. in. = 6.452 cm^2

1 sq. ft. = 929.03 cm^2

1 acre = 43,560 ft^2 = 4.047 x 10^{3}m^2

1 sq mile = 640 acres = 2.590 km^2

Weight

1 lb = 435.59 g = 16 oz = 7000 grains

Water Quality

1ppm = 1 mg/l

1 grain/U.S. gal = 17.1 ppm

1 taf = 735 ppm

Discharge

1 cfs = 449 gal/min

= 6.46 x 10^5 gal/day

= 1.98 acre-ft/day

= 28.3 liters/sec

Density

Water: 1 cm^3 = 0.999g at 60°F

= 0.998 g at 20°C

1 ft^3 = 1.938 slugs at 60°F

=1.936slugs at 15°C

Viscosity

Water : 1.124 centipoises at 60°F

1.005 centipoises at 20°C

1 centipoise = 0.01 poise = 0.01 dyne-sec/cm^2

1 lb-sec/ft^2 = 478.8 poises

Pressure

1ft water at 4°C = 2.242 cm Hg

= 0.4335 lb/in^2

Permeability

(K_s = lab. coef. of permeability)

1 K_s = 4.72 x 10^{-5} cm/sec.

1 darcy = 0.987 x 10^{-8} cm^2

= 1.062 x 10^{-11} ft^2

= 18.2 K_s (for water at 60°F)

= 0.966 x 10^{-3} cm/sec

(for water at 20°C)

1 cm/sec = 1.02 x 10^{-5}cm^2

(for water at 20°C)

Appendix 3

PLANETS IN SOLAR SYSTEM

Planet	Diameter	Mass	Density	Gravity	No. of Satellites	Time for One Rotation On Axis (Earth Hours/) Days)	Time for One Revolution around Sun (Earth Years)	Distance from sun	
	(km)	(Earth=1)	(Water=1)	(Earth=1)				(10^6 Km)	(10^6 mi)
Inner Planets									
Mercury	4835	0.055	5.69	0.38	0	59 days	0.241	57.7	36.8
Venus	12194	0.815	5.16	0.89	0	243 days	0.616	107.0	66.9
Earth	12756	1.000	5.52	1.00	1	1.00 days	1.00	149.6	92.6
Mars	6760	0.108	3.89	0.38	2	1.03 days	1.88	226.0	141.0
Outer Planets									
Jupiter	141600	318.0	1.25	2.64	15	9.83 h	11.99	775	482
Saturn	120800	95.1	0.62	1.17	18	10.23 h	29.5	1421	883
Uranus	47100	14.5	1.60	1.03	5	23.00 h	84.0	2861	1777
Neptune	44600	17.0	2.21	1.50	8	22.00 h	165.0	4485	2787
Pluto	14000?	0.8?	4.2?	?	1	6.39 days	248.0	5886	3658

INDEX

Acidity & Alkalinity 43
Aeolian Deposits 21
Agricultural pollution 49
Alluvium 77
Aquiclude 30
Aquifer 29
Aquifuge 30
Aquitard 30
Artesian springs 27
Artificial recharge 61
Basin Investigations 67
Boron 47
Calcium 44
Capillary zone 24
Carbonate and biocarbonates 44
Carbonate rocks 22
Chemical quality of water 42
Chlorides 45
Coefficient of permeability 37
Colour 41
Cone of depression 91
Confined aquifer 31
Conjective use 68
Connate water 20
Constant Head Permeameter 38
Crystalline rocks 22
Cuddapahs (Geological) 79
Darcy's law 36
Deccan trap province 76
Domestic pollution 49
Effective porosity 34
Electrial resistivity method 59
Electrical conductivity 42
Evaporation 17
Evapo-Transpiration 17
Fluorides 45
Fluvial deposits 21
Foam 41
Forms of Groundwater 26
Ganges-Brahmaputra
    Alluvial province 73
Geohydrology 11
Geological investigations 53
Geophysical investigations 57
Geyser 27
Ghyben-Herzberg relation 64
Glacial deposits 21
Gondwana sedimentary
    province 71,76
Gravity method 57
Groundwater basin 66
Hardness of water 42
Himalayan highland province 73
Hydrogeobotanical
    prospecting 55
Hydrogeological explaration 56
Hydrogeology 11
Hydrologic cycle 14
Hydrologic equation 15
Hydrological investigations 56
Hydrological significance of
    watersheds 63
Hydrology 11
Idealised aquifer 31
Industrial pollution 50
Infiltration 18
Inflow and Outflow 67
Interface 64
Intermediate zone 24
Iron 46

Isohyets 17
Juvenile water 20
Laterites and Alluvium 80
Leaky aquifer 31
Magenisum 49
Magnetic method 58
Marine water 19
Metamorphic water 20
Meteoric water 19
Mining activities 51
Nitrates 45
Occurrence of Groundwater 21
Odour 41
Oil-field brines 51
Origin of groundwater 19
Peninsular Provinces 70
Perched aquifer 31
Permeability 35
p^H 42
Physical quality of water 41
Pollution 48
Porosity 33
Potassium 44
Precipitation 16
Primary Porosity 34
Quality of groundwater 40
Recharge & Discharge areas 28
Resistivity 59
Runoff 18
Sandstones 22
Sea water intrusion 64
Secondary porosity 34
Seismic method
Silicon 46
Sodium 44
Soil water zone 24
Specific retention 38
Specific yield 38
Springs 27
Sulphates 45
Taste 41
Temperature 41
Total dissolved solids 43
Transmissibility 37
Transpiration 17
Turbidity 41
Unconfined aquifer 30
Urban Pollution 49
Vadose water 24
Vertical distribution of groundwater 23
Watershed 63
Water table 26
Wenner arrangement 60
Zone of aeration 24
Zone of saturation 25

❑

BIBLIOGRAPHY

This list is not an exhaustive list of books consulted but rather a selection of those recommended for further reading.

i) Encyclopedia of Geological Sciences
- Daniel N. Lapeds

ii) Hydrogeology
- Davies & Dawiest

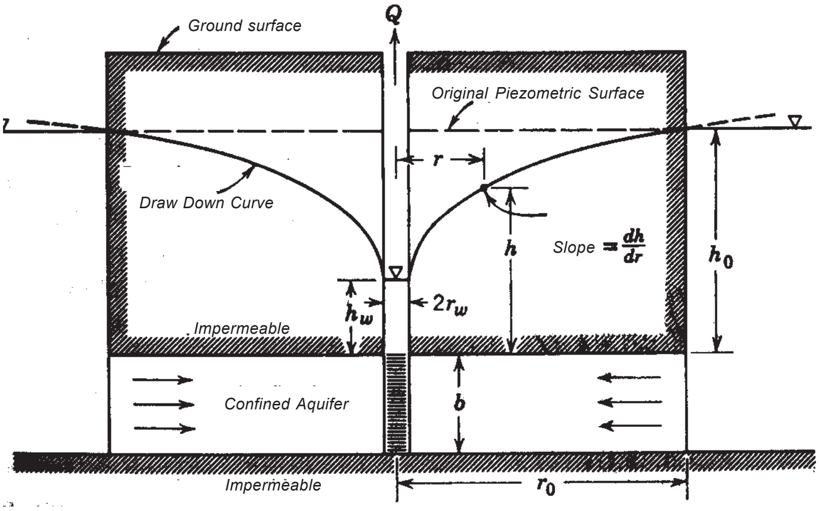
iii) Groundwater Hydrology
- D.K. Todd

iv) Groundwater Assesment, Development and Management
- Karanth

v) Introductory Geology
- R.W. Ojakangas

vi) Groundwater Studies
- UNESCO

Basic Principles of Hydrogeology



Cone of depression

Rao R.M.
Subrahmanyam A.

Sun, Earth, Seasons and Water: What *Rigveda* Says

Thou dost protect and purify everything, O Sun! Praised be Thy light in which Thou dost look after and feed this world and all living things. Fire Thou art that dost originate in Ocean, Sky and Space, O Sun! Thou art Fire That divideth seasons and produceth the sequence of living beings on Earth. Thou risest from the east, O Sun! watchest the Universe and destroyest invisible, poisonous creatures. Thou art the Father, O Sun! Whom Mother Earth doth worship through 'Yajna'. Deciding to produce varieties of Crops, Thou generatest the emboyo irrigated with water inside the earth.

Feed on fine grass, O Cows! ; drink ye of ponds clean, safe water; procreate, and give birth to calves.

Water be ever the same: It riseth up and cometh down in rain. Clouds gladden the Earth and Fire pleaseth the heaven.

PUBLISHER
SADHANA GRANDHA MANDALI
TENALI - 522 201, A.P.